PROPERTIES OF ENGINEERING MATERIALS FOR USE IN ROTATING MACHINERY AT CRYOGENIC TEMPERATURES

pt.2

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PT. 21

PROPERTIES OF ENGINEERING MATERIALS FOR USE IN ROTATING MACHINERY AT CRYOGENIC TEMPERATURES

by

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MATERIAL	% Elongation (upper temp)	% Elongation (lowest temp)	% Red. in Area (upper temp)	% Red. in Area (lowest temp)
Commercially Pure Ti[8]	30 (RT)	30 (20°K)	51 (RT)	56 (20°K)
Commercial Grade Ti[7], RS-70 sheet, annealed	35 (RT)	14 (20°K)	NO DATA	NO DATA
Ti-5Al-2.5Sn[5,8], sheet, annealed	15 (RT)	6 (20°K)	28 (RT)	9 (20°K)
Ti-5Al-2.5Sn[5], bar	13 (RT)	3 (20°K)	28 (RT)	9 (20°K)
Ti-5Al-2.5Sn[8], normal interstitial	17 (RT)	5 (20°K)	NO DATA	NO DATA
Ti-5Al-2.5Sn[8], extra low interstitial	17 (RT)	12 (20°K)	NO DATA	NO DATA
Ti-5Al-2.5Sn[8], annealed, normal interstitial	NO DATA	NO DATA	44 (RT)	18 (20°K)
Ti-5Al-4Zr-1V[5], sheet, annealed	16 (RT)	4.5 (20°K)	NO DATA	NO DATA
Ti-5Al-5Zr-5Sn[5], sheet, annealed	17 (RT)	10 (20°K)	NO DATA	NO DATA
Ti-7Al-12Zr[6,8], sheet, annealed	13 (RT)	5.5 (20°K)	NO DATA	NO DATA

Table 4.21 Percentage Elongation and Percentage Reduction in Area of Titanium and Titanium Alloys

MATERIAL	% Elongation (upper temp)	% Elongation (lowest temp)	% Red. in Area (upper temp)	% Red. in Area (lowest temp)
Ti-8Al-2Cb-1Ta[5,8], sheet	13 (RT)	1 (20°K)	NO DATA	NO DATA
Ti-8Al-2Cb-1Ta[8], sheet, annealed	5 (RT)	1.5 (20°K)	NO DATA	NO DATA
Ti-8Al-1Mo-1V[8], sheet, annealed	16 (RT)	2.5 (20°K)	NO DATA	NO DATA
Ti-8Al-1Mo-1V[8], sheet, duplex annealed	16 (RT)	2 (20°K)	NO DATA	NO DATA
<u>TITANIUM-ALPHA BETA</u>				
Ti-4Al-3Mo-1V[5], sheet, soln treated, aged	8.2 (RT)	1.5 (20°K)	NO DATA	NO DATA
Ti-5Al-4V[7], sheet, annealed	13 (RT)	2 (20°K)	NO DATA	NO DATA
Ti-6Al-4V[5,8], sheet, annealed	14 (RT)	1.5 (20°K)	NO DATA	NO DATA
Ti-6Al-4V[5], bar	14 (RT)	2 (20°K)	46 (RT)	3 (20°K)
Ti-6Al-4V[8], annealed, normal interstitial	12 (RT)	3 (20°K)	48 (RT)	31 (20°K)

Table 4.21 Percentage Elongation and Percentage Reduction in Area of Titanium and Titanium Alloys (cont.)

MATERIAL	% Elongation (upper temp)	% Elongation (lowest temp)	% Red. in Area (upper temp)	% Red. in Area (lowest temp)
Ti-6Al-4V[8], extra low interstitial	12.5 (RT)	5 (20°K)	NO DATA	NO DATA
Ti-6Al-6V-2Sn[8], annealed	18 (RT)	10 (4.2°K)	40 (RT)	26 (4.2°K)
Ti-6Al-6V-2Sn[8], soln treated, aged	8 (RT)	3 (4.2°K)	18 (RT)	20 (4.2°K)
TITANIUM-BETA				
Ti-13V-11Cr-3Al[7], sheet, cold rolled, annealed	28 (RT)	0 (20°K)	NO DATA	NO DATA
Ti-13V-11Cr-3Al[8], soln treated	27 (RT)	0 (20°K)	56 (RT)	3 (20°K)

Table 4.21 Percentage Elongation and Percentage Reduction in Area of Titanium and Titanium Alloys (cont.)

MATERIAL	% Elongation (upper temp)	% Elongation (lowest temp)	% Red. in Area (upper temp)	% Red. in Area (lowest temp)
MAGNESIUM ALLOYS				
AZ31B-0[5,7,20], wrought sheet	25.5 (RT)	7 (20°K)	NO DATA	NO DATA
ZE10A-H11[5,20], sheet, cold worked	29.5 (RT)	11 (20°K)	NO DATA	NO DATA
HM31A-F[5,7,20], extruded	9.5 (RT)	11 (20°K)	NO DATA	NO DATA
HM21A-T8[5,7,20], wrought sheet	8 (RT)	8 (20°K)	NO DATA	NO DATA
HK31A-T6[5,7,20], sand cast	10 (RT)	4.5 (20°K)	NO DATA	NO DATA
HK-31A-0[5,7,20], wrought sheet	36 (RT)	11 (20°K)	NO DATA	NO DATA
ZK60A-T5[7], extruded	26 (RT)	3 (20°K)	NO DATA	NO DATA
COBALT ALLOYS				
Haynes 25[5], sheet 20% cold rolled	16.5 (RT)	19 (20°K)	NO DATA	NO DATA
Haynes 25[5], sheet 40% cold rolled	3 (RT)	1 (20°K)	NO DATA	NO DATA

Table 4.22 Percentage Elongation and Percentage Reduction in Area of Miscellaneous Metals

MATERIAL	% Elongation (upper temp)	% Elongation (lowest temp)	% Red. in Area (upper temp)	% Red. in Area (lowest temp)
Elgiloy[8], bar, 45% cold red	11 (RT)	7 (20°K)	47 (RT)	31 (20°K)
OTHERS				
Tantalum[5], bar, wrought, stress relieved	28 (RT)	NO DATA	96 (RT)	90 (20°K)
Tantalum[5], bar, recrystallized	65 (RT)	28 (20°K)	98 (RT)	86 (20°K)
Columbium[5], bar, wrought, stress relieved relieved	32 (RT)	3 (20°K)	96 (RT)	9 (20°K)
Columbium[5], bar, recrystallized	60 (RT)	2 (20°K)	94 (RT)	28 (20°K)
Commercially Pure Lead[7] cast	30 (RT)	37 (20°K)	NO DATA	NO DATA

Table 4.22 Percentage Elongation and Percentage Reduction in Area of Miscellaneous Metals (cont.)

MATERIAL	% Elongation (upper temp)	% Elongation (lowest temp)	% Red. in Area (upper temp)	% Red. in Area (lowest temp)
TFE Teflon[8], sheet, 25% Asbestos filled	15 (RT)	0 (20°K)	NO DATA	NO DATA
FEP Teflon[8], 20% glass filled	40 (RT)	0 (20°K)	NO DATA	NO DATA
TFE Teflon[8], sheet, 116 glass cloth	20 (RT)	2 (20°K)	NO DATA	NO DATA
FEP Teflon[8], sheet, 116 glass cloth	16 (RT)	2 (20°K)	NO DATA	NO DATA
EPOXY-FIBERGLASS LAMINATE-S/901 ROVING REINFORCEMENT-PANELS				
E-787 Resin[8], unidirectional filament, parallel to reinf.	4.4 (RT)	5.1 (20°K)	NO DATA	NO DATA
E-787 Resin[8], 1543 cloth reinf., parallel to reinf.	3.6 (RT)	5.6 (20°K)	NO DATA	NO DATA
E-787 Resin[8], bidirectional reinf., parallel to reinf.	3.5 (RT)	4.1 (20°K)	NO DATA	NO DATA
DER-332/BF_3 Resin[8], bidirectional filament	3.5 (RT)	3.9 (20°K)	NO DATA	NO DATA

Table 4.23 Percentage Elongation and Percentage Reduction in Area of Composite Materials

MATERIAL	% Elongation (upper temp)	% Elongation (lowest temp)	% Red. in Area (upper temp)	% Red. in Area (lowest temp)
DER-332/DEH 50 Resin[8], bidirectional filament	3.4 (RT)	4 (20°K)	NO DATA	NO DATA
POLYESTER-FIBERGLASS LAMINATE				
Selectron 5158 Resin[8], S/901 roving bidirectional filament, parallel to reinf.	3 (RT)	3.5 (20°K)	NO DATA	NO DATA

Talbe 4.23 Percentage Elongation and Percentage Reduction in Area of Composite Materials (cont.)

MATERIAL	% Elongation (upper temp)	% Elongation (lowest temp)	% Red. in Area (upper temp)	% Red. in Area (lowest temp)
Mylar[8], 15% crystallinity	97 (RT)	8 (20°K)	NO DATA	NO DATA
Mylar[8], 55% crystallinity	102 (RT)	0 (20°K)	NO DATA	NO DATA
TFE Teflon[8], 49-66% crystallinity	175 (RT)	0 (20°K)	NO DATA	NO DATA
FEP Teflon[8], 44-49% crystallinity	365 (RT)	2 (20°K)	NO DATA	NO DATA
KEL-F[8], sheet, 40-70% crystallinity	140 (RT)	1 (20°K)	NO DATA	NO DATA
KEL-F[8], type 81, sheet, 40-65% crystallinity	140 (RT)	5 (20°K)	NO DATA	NO DATA
DER-332/DEH 50 resin[8],	5 (RT)	1.1 (20°K)	NO DATA	NO DATA
E-787 resin[8]	2 (RT)	0.7 (20°K)	No DATA	NO DATA
DER-332/BF_3 resin[8]	1.5 (RT)	0.8 (20°K)	NO DATA	NO DATA

Table 4.24 Percentage Elongation and Percentage Reduction in Area of Polymers

MATERIAL	ν (upper temp)	ν (lowest temp)
Pure Aluminum[5]	0.347 (RT)	0.331 (4.2°K)
AISI/SAE 4340 Steel[5] annealed	0.287 (RT)	0.268 (4.2°K)
AISI 301 Stainless[5] Steel	0.307 (RT)	0.292 (20°K)
Pure Ti[5,8]	0.338 (RT)	0.305 (4.2°K)
Ti-6Al-4V[8], extra low interstitial	0.323 (RT)	0.297 (20°K)
Ti-7Mn[5]	0.313 (RT)	0.302 (4.2°K)
Pure Magnesium[5]	0.308 (RT)	0.295 (4.2°K)

Table 4.25 Poisson's Ratio of Various Materials

MATERIAL	τ_{uts} (upper temp)	τ_{uts} (lowest temp)
2014-T6[8], sheet, longitudinal	45000 (RT)	60000 (20°K)
2014-T6[8], sheet, transverse	44000 (RT)	61000 (20°K)
2219-T6[8], sheet, longitudinal	37000 (RT)	62000 (20°K)
2219-T6[8], sheet, transverse	42000 (RT)	64000 (20°K)
2219-T81[8], sheet	42000 (RT)	58000 (20°K)
2219-T87[8], sheet	43000 (RT)	65000 (20°K)
6061-T6[8], sheet	32000 (RT)	52000 (20°K)
7039-T6[8], sheet longitudinal	40000 (RT)	54000 (20°K)
7039-T6[8], sheet, transverse	40000 (RT)	48000 (20°K)
Inconel X[8], sheet, soln treated, aged, longitudinal	112000 (RT)	147000 (20°K)
Inconel X[8], sheet, soln treated, aged, transverse	115000 (RT)	142000 (20°K)
D-979[8], sheet, annealed	102000 (RT)	125000 (20°K)
E-787 Resin[8], S/901 cloth reinf.	8000 (RT)	10000 (20°K)
E-787 Resin[8], S/901 1543 cloth reinf.	8000 (RT)	10300 (20°K)
E-787 Resin[8], S/901 cloth reinf., unidirectional filament	8000 (RT)	8900 (20°K)

Table 4.26 Shear Strength of Various Materials in PSI

MATERIAL	τ_{uts} (upper temp)	τ_{uts} (lowest temp)
E-787 Resin[8], S/901 cloth reinf., bidirectional filament	5300 (RT)	6700 (20°K)
DER 332/DEH 50 Resin[8] S/901 cloth reinf., bidirectional filament	5000 (RT)	9300 (20°K)
DER 332/BF_3 Resin[8] S/901 cloth reinf., bidirectional filament	3200 (RT)	4600 (20°K)
Selectron 5158 Resin[8] S/901 cloth reinf., bidirectional filament	3300 (RT)	3300 (20°K)

Table 4.26 Shear Strength of Various Materials in PSI (cont.)

MATERIAL	G (upper temp)	G (lowest temp)
Pure Aluminum[5]	3.8×10^6 (RT)	4.3×10^6 (4.2°K)
AISI/SAE 4340 Steel[5] annealed	11.5×10^6 (RT)	12.5×10^6 (4.2°K)
AISI 301 Stainless[5] Steel	11.4×10^6 (RT)	12.5×10^6 (4.2°K)
Ti-6Al-4V[5], Titanium Alloy	6.1×10^6 (RT)	6.9×10^6 (4.2°K)
Ti-7Mn[5], Titanium Alloy	6.1×10^6 (RT)	6.9×10^6 (4.2°K)
Pure Titanium[5]	5.7×10^6 (RT)	6.6×10^6 (4.2°K)
Pure Magnesium[5]	2.4×10^6 (RT)	2.7×10^6 (4.2°K)
Pure Molybdenum[5]	16.5×10^6 (RT)	17.2×10^6 (4.2°K)

Table 4.27 Modulus of Ridigidy of Various Materials in PSI

MATERIAL	Impact Energy (upper temp)	Impact Energy (lowest temp)
1100-0[7,8], bar, (Izod)	19 (RT)	25 (80°K)
1100[17], 3/4 hard, (Charpy k-notch)	27 (RT)	36 (20°K)
1100-H14[7,8], bar, (Charpy v-notch)	71 (RT)	75 (20°K)
1100-H16[7,8], bar, (Charpy k-notch)	29 (RT)	38 (20°K)
2014-T6[8], plate, (Charpy v-notch)	2.5 (RT)	4 (20°K)
2020-T6[8], bar, (Charpy v-notch)	1.5 (RT)	15 (77.6°K)
2024-T4[7,8], bar, (Charpy v-notch)	9.5 (RT)	7 (20°K)
2024-T86[8], bar, (Charpy v-notch)	3.5 (RT)	3.5 (20°K)
3003-H12[7], bar, (Charpy k-notch)	17 (RT)	22 (75°K)
5052-F[7], plate, (Charpy v-notch)	100 (RT)	48 (20°K)
5086-0[7,19], (Charpy v-notch)	13.5 (RT)	10.7 (20°K)
5154-0[7], (Charpy v-notch)	98 (RT)	53 (20°K)
5456-H343[8], plate, (unspecified), longitudinal	9.5 (RT)	7.5 (20°K)
5456-H343[8], plate, (unspecified), transverse	6 (RT)	5 (20°K)
6053-T6[7], bar, (Charpy k-notch)	80 (RT)	80 (75°K)

Table 4.28 Impact Energy of Aluminum and Aluminum Alloys in Foot-Pounds

MATERIAL	Impact Energy (upper temp)	Impact Energy (lowest temp)
6061-T[17], (Charpy k-notch)	10 (RT)	12 (20°K)
6061-T6[7], bar, (Charpy k-notch)	9 (RT)	12 (20°K)
6061-T6[8], plate, (Charpy v-notch), longitudinal	12.5 (RT)	13 (20°K)
6061-T6[8], plate, (Charpy v-notch), transverse	9 (RT)	10 (20°K)
7039-T6[8], plate, (Charpy v-notch), longitudinal	7.5 (RT)	7.5 (20°K)
7039-T6[8], plate, (Charpy v-notch), transverse	6 (RT)	4 (20°K)
7039-T61[8], plate, (Charpy v-notch), longitudinal	13 (RT)	9 (20°K)
7039-T61[8], plate (Charpy v-notch), transverse	8 (RT)	6 (20°K)
7075-T[17], (Charpy k-notch)	5 (RT)	5 (20°K)
7075-T6[7,8], rod, (Charpy v-notch)	5.5 (RT)	4 (20°K)
7075-T6[7,8], rod, (Charpy k-notch)	4 (RT)	5 (20°K)
7075-T6[7], extrusions (Izod)	7 (RT)	NO DATA

Table 4.28 Impact Energy of Aluminum and Aluminum Alloys in Foot-Pounds (cont.)

MATERIAL	Impact Energy (upper temp)	Impact Energy (lowest temp)
7079-T6[7], forged, (Charpy v-notch)	4 (RT)	3 (20°K)
195-T6[7], sand cast, (Charpy k-notch)	2 (RT)	2 (75°K)
356-T6[7], sand cast, (Charpy k-notch)	1 (RT)	1 (75°K)

Table 4.28 Impact Energy of Aluminum and Aluminum Alloys in Foot-Pounds (cont.)

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
2014-T6[8], sheet, (k_t=3.5)	75500 (RT)	101000 (20°K)
2014-T6[8], sheet, (k_t=3.8)	77000 (RT)	103000 (20°K)
2014-T6[8], sheet, (k_t=7.2)	76000 (RT)	84000 (20°K)
2014-T6[8], sheet, (k_t=8)	70000 (RT)	82000 (20°K)
2014-T6[8], sheet, (k_t=13)	63000 (RT)	73000 (20°K)
2014-T6[8], sheet, (k_t=21)	63500 (RT)	70000 (20°K)
2014-T651[8], plate, (k_t=16)	83000 (RT)	102000 (20°K)
2219-T62[8], sheet, (k_t=3.5), longitudinal	63000 (RT)	92000 (20°K)
2219-T62[8], sheet, (k_t=3.5), transverse	67000 (RT)	88000 (20°K)
2219-T62[8], sheet, (k_t=8), longitudinal	57000 (RT)	73000 (20°K)
2219-T62[8], sheet, (k_t=8), transverse	57000 (RT)	74000 (20°K)
2219-T62[8], sheet, (k_t=21), longitudinal	47000 (RT)	67000 (20°K)
2219-T62[8], sheet, (k_t=21), transverse	47000 (RT)	58000 (20°K)
2219-T851[8], plate (k_t=16)	84000 (RT)	106000 (4.2°K)

Table 4.29 Notched Tensile Strength of Aluminum and Aluminum Alloys in PSI

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
2618-T6[8], sheet, (k_t=3.5), longitudinal	64000 (RT)	89000 (20°K)
2618-T6[8], sheet, (k_t=3.5), transverse	63000 (RT)	85000 (20°K)
2618-T6[8], sheet, (k_t=8), longitudinal	60000 (RT)	75000 (20°K)
2618-T6[8], sheet, (k_t=8), transverse	57000 (RT)	71000 (20°K)
2618-T6[8], sheet, (k_t=13), longitudinal	57000 (RT)	71000 (20°K)
2618-T6[8], sheet, (k_t=13), transverse	55000 (RT)	67000 (20°K)
2618-T62[8], sheet, (k_t=3.5), longitudinal	64000 (RT)	88000 (20°K)
2618-T62[8], sheet, (k_t=3.5), transverse	64000 (RT)	85000 (20°K)
2618-T62[8], sheet, (k_t=8), longitudinal	59000 (RT)	71000 (20°K)
2618-T62[8], sheet, (k_t=8), transverse	57000 (RT)	69000 (20°K)
2618-T651[8], plate (k_t=16)	82000 (RT)	98000 (4.2°K)
5052-H38[8], sheet, (k_t=7.2), longitudinal	46500 (RT)	77500 (20°K)
5052-H38[8], sheet, (k_t=7.2), transverse	50000 (RT)	79000 (20°K)
5083-0[8,24], plate, (k_t=14)	50500 (RT)	63000 (4.2°K)

Table 4.29 Notched Tensile Strength of Aluminum and Aluminum Alloys in PSI (cont.)

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
5083-H39[8], sheet, (k_t=7.2), longitudinal	69000 (RT)	91000 (20°K)
5083-H39[8], sheet, (k_t=7.2), transverse	77000 (RT)	96000 (20°K)
5083-H113[8,24], plate, (k_t=14)	62000 (RT)	73500 (4.2°K)
5086-0[24], plate, (k_t=14)	47000 (RT)	60000 (20°K)
5086-H34[8], sheet, (k_t=7.2), longitudinal	48000 (RT)	72000 (20°K)
5086-H34[8], sheet, (k_t=7.2), transverse	47000 (RT)	58000 (20°K)
5086-H34[8], sheet, (k_t=10)	47000 (RT)	65000 (20°K)
5086-H34[8], sheet, (k_t=11)	89000 (RT)	86000 (20°K)
5086-H34[24], plate, (k_t=14)	63000 (RT)	73000 (20°K)
5154-H38[8], sheet (k_t=7.2), longitudinal	49000 (RT)	77500 (20°K)
5154-H38[8], sheet, (k_t=7.2), transverse	54000 (RT)	77500 (20°K)
5456-0[24], plate (k_t=14)	50000 (RT)	60000 (20°K)
5456-H321[24], plate, (k_t=14)	59000 (RT)	71000 (20°K)
6061-T6[8], sheet, (k_t not given)	48000 (RT)	70000 (20°K)

Table 4.29 Notched Tensile Strength of Aluminum and Aluminum Alloys in PSI (cont.)

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
6061-T651[8], plate, (k_t not given), longitudinal	69000 (RT)	90000 (4.2°K)
6061=T651[8], plate, (k_t not given), transverse	68000 (RT)	87000 (4.2°K)
7002-T6[8], plate, (k_t=7.2), longitudinal	92000 (RT)	103000 (20°K)
7002-T6[8], plate, (k_t=7.2), transverse	87000 (RT)	97000 (20°K)
7002-T6[8], plate, (k_t=13), longitudinal	70000 (RT)	89000 (20°K)
7002-T6[8], plate, (k_t=13), transverse	70000 (RT)	81000 (20°K)
7039-T6[8], sheet, (k_t=3.5), longitudinal	69000 (RT)	94000 (20°K)
7039-T6[8], sheet, (k_t=3.5), transverse	71000 (RT)	92000 (20°K)
7039-T6[8], sheet, (k_t=8), longitudinal	66000 (RT)	79000 (20°K)
7039-T6[8], sheet, (k_t=8), transverse	63000 (RT)	69000 (20°K)
7075-T6[8], sheet, (k_t=7.2), longitudinal	76000 (RT)	87000 (20°K)
7075-T6[8], sheet, (k_t=7.2), transverse	75000 (RT)	82000 (20°K)
7079-T6[8], sheet, (k_t=7.2), longitudinal	84000 (RT)	78000 (20°K)

Table 4.29 Notched Tensile Strength of Aluminum and Aluminum Alloys in PSI (cont.)

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
7079-T6 (8), sheet, (k_t=7.2), transverse	82000 (RT)	77000 (20°K)
7079-T6 (8), sheet, (k_t=21), longitudinal	71000 (RT)	59000 (20°K)
7079-T6 (8), sheet, (k_t=21), transverse	62000 (RT)	43000 (20°K)
7079-T6 (8), billet, (k_t=7.2), longitudinal	94000 (RT)	65000 (20°K)
7079-T6 (8), billet, (k_t=7.2), transverse	89000 (RT)	55000 (20°K)
7178-T6 (8), sheet, (k_t=7.2), longitudinal	92000 (RT)	62000 (20°K)
7178-T6 (8), sheet, (k_t=7.2), transverse	84000 (RT)	56000 (20°K)
7178-T6 (8), sheet, (k_t=21), longitudinal	47000 (RT)	32000 (20°K)
7178-T6 (8), sheet, (k_t=21), transverse	52000 (RT)	32000 (20°K)
7178-T6 (8), plate, (k_t=10)	64000 (RT)	38000 (20°K)
354-T62 (25), plate, (k_t>16), permanent mold cast	54200 (RT)	57200 (20°K)
356-T61 (8), cast, (k_t=16)	42000 (RT)	62000 (4.2°K)
356-T62 (25), plate, (k_t>16), permanent mold cast	46200 (RT)	63300 (20°K)
B-218-F (25), sand cast, (k_t>16)	43800 (RT)	20000 (20°K)

Table 4.29 Notched Tensile Strength of Aluminum and Aluminum Alloys in PSI (cont.)

MATERIAL	IMPACT ENERGY (upper temp)	IMPACT ENERGY (lowest temp)
PURE COPPER		
Pure Copper[22], annealed (Charpy v-notch)	61 (RT)	72 (20°K)
Pure Copper[22], aged, (Charpy v-notch)	90 (RT)	115 (20°K)
Pure Copper[22], 60% cold drawn, (Charpy v-notch)	95 (RT)	83 (20°K)
OFHC Copper[7], annealed, (Charpy k-notch)	57 (RT)	72 (20°K)
OFHC Copper[7], annealed, (Izod)	42 (RT)	50 (90°K)
OFHC Copper[8], 60% cold reduced, (Charpy v-notch)	95 (RT)	83 (20°K)
OFHC Copper[18], (Charpy key-hole)	56 (RT)	72 (20°K)
COPPER-ZINC ALLOYS (BRASS)		
Commercial Bronze[8,22] 90Cu,10Zn, annealed, (Charpy v-notch)	115 (RT)	117 (20°K)
Red Brass[8], 84.7Cu,15.3Zn, 14% cold reduced, (Charpy v-notch)	96 (RT)	76 (20°K)
Admiralty Brass[8], 72.5Cu,27.5An, annealed, (Charpy v-notch)	107 (RT)	109 (20°K)

Table 4.30 Impact Energy of Copper and Copper Alloys in Foot-Pounds

MATERIAL	IMPACT ENERGY (upper temp)	IMPACT ENERGY (lowest temp)
60Cu,39Zn,1Sn[22], annealed, (Charpy v-notch)	37 (RT)	35 (20°K)
Naval Brass[8], 60.3Cu,39.7Zn, annealed, (Charpy v-notch)	38 (RT)	30 (20°K)
COPPER-TIN ALLOYS (BRONZE)		
Aluminum Bronze D[8], annealed, (Charpy v-notch)	110 (RT)	66 (20°K)
Nickel Aluminum [8] Bronze, sand cast, (Charpy v-notch)	10 (RT)	6 (20°K)
Phosphor Bronze A[8,22] 85% cold drawn, (Charpy v-notch)	106 (RT)	51 (20°K)
Phosphor Bronze D[22], 37% cold drawn, (Charpy v-notch)	50 (RT)	20 (20°K)
COPPER SILICON ALLOYS		
Silicon Bronze A[8], annealed, (Charpy v-notch)	112 (RT)	117 (20°K)
Silicon Bronze[22], hard, (Charpy v-notch)	73 (RT)	52 (20°K)
COPPER-NICKEL ALLOYS		
Copper Nickel 10[8,22] annealed, (Charpy v-notch)	114.5 (RT)	115.5 (20°K)

Table 4.30 Impact Energy of Copper and Copper Alloys in Foot-Pounds (cont.)

MATERIAL	IMPACT ENERGY (upper temp)	IMPACT ENERGY (lowest temp)
Copper Nickel 30[8,22] annealed, (Charpy v-notch)	115 (RT)	115 (20°K)
Copper-Nickel-[8] Silicon, aged, (not specified)	110 (RT)	116 (20°K)
<u>COPPER-BERYLLIUM ALLOYS</u>		
Beryllium Copper[7], wrought, cold drawn, 1/2 hard, 97.7Cu,2Be, 0.3Co, (Charpy v-notch)	72 (RT)	55 (20°K)
Beryllium Copper[7], wrought, cold drawn, 1/2 hard, age hardened, 97.7Cu,2Be,0.3Co, (Charpy k-notch)	7 (RT)	8 (90°K)
Beryllium Copper[7], wrought, soln treated, 97.7Cu, 2Be, 0.3Co, (Charpy k-notch)	105 (RT)	75 (90°K)
Beryllium Copper[7], cast, soln treated, age hardened, 97.4Cu, 2Be, 0.6Co, (Charpy k-notch)	2 (RT)	2 (90°K)
Beryllium Copper[8], 1/2 hard, (Charpy v-notch)	72 (RT)	50 (20°K)

Table 4.30 Impact Energy of Copper and Copper Alloys in Foot-Pounds (cont.)

MATERIAL	IMPACT ENERGY (upper temp)	IMPACT ENERGY (lowest temp)
Beryllium Cobalt[7] Bronze, wrought, cold drawn to 1/2 hard, 96.8Cu, 2.6Co, 0.6Be, (Charpy v-notch)	23 (RT)	24 (20°K)
Beryllium Cobalt[7] Bronze, cast, soln treated, aged hardened, 96.8Cu,2.6Co,0.6Be, (Charpy k-notch)	10 (RT)	12 (90°K)
Beryllium Zinc[7] Bronze, wrought, cold drawn, 1/4 hard, age hardened, 98Cu, 1.1Be,0.9Zn, (Charpy k-notch)	12 (RT)	12 (90°K)

Table 4.30 Impact Energy of Copper and Copper Alloys in Foot-Pounds (cont.)

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
COPPER-ZINC ALLOYS (BRASS)		
Commercial Bronze[8,22] 90Cu, 10Zn, (k_t=4.7)	50000 (RT)	79000 (4.2°K)
Red Brass[8], 84.7Cu, 15.3Zn, 19% cold reduced, (k_t=4.7)	54000 (RT)	74000 (4.2°K)
Admiralty Brass[8], 72.5Cu, 27.5Zn, annealed, (k_t=4.7)	54000 (RT)	86000 (4.2°K)
Naval Brass[8], 60.3Cu, 39.7Zn, annealed, (k_t=4.7)	75000 (RT)	115000 (4.2°K)
COPPER-TIN ALLOYS (BRONZE)		
Aluminum Bronze D[8], annealed, (k_t=4.7)	122000 (RT)	160000 (4.2°K)
Nickel Aluminum Bronze[8], sand cast, (k_t=4.7)	105000 (RT)	119000 (4.2°K)
Phosphor Bronze A[8,22], 85% cold drawn, (k_t=4.7)	135000 (RT)	185000 (4.2°K)
Silicon Bronze A[8], annealed, (k_t=4.7)	80000 (RT)	121000 (4.2°K)
COPPER-NICKEL ALLOYS		
Copper Nickel 10[8,22], annealed, (k_t=4.7)	65000 (RT)	100000 (4.2°K)
Copper Nickel 30[8,22], annealed, (k_t=4.7)	80000 (RT)	130000 (4.2°K)
Copper-Nickel-Silicon[8], aged, (k_t=4.7)	190000 (RT)	215000 (4.2°K)

Table 4.31 Notched Tensile Strength of Copper and Copper Alloys in PSI

MATERIAL	Impact Energy (upper temp)	Impact Energy (lowest temp)
Commercially Pure Nickel[7], annealed, (Charpy v-notch)	215 (RT)	235 (75°K)
Commercially Pure Nickel[7], annealed, (Izod)	90 (RT)	100 (90°K)
Commercially Pure Nickel[7], cold drawn, (Charpy v-notch)	185 (RT)	212 (80°K)
Commercially Pure Nickel[7], hot rolled, (Charpy v-notch)	195 (RT)	230 (80°K)
Commercially Pure Nickel[7], as cast, (not specified)	35 (RT)	38 (78°K)
Hastelloy B[7], (Charpy u-notch)	38 (RT)	33 (20°K)
Hastelloy C[7,18], (Charpy v-notch)	56 (RT)	44 (20°K)
Hastelloy X[8], (Charpy v-notch)	76 (RT)	38 (20°K)
Inconel 718[8], forging, annealed, aged, longitudinal, (Charpy v-notch)	50 (RT)	43 (20°K)
Inconel 718[8], forging, annealed, aged, transverse, (Charpy v-notch)	20 (RT)	25 (20°K)
René 41[8], bar, soln treated, (Charpy v-notch)	15 (RT)	11 (20°K)
AL-718[6], bar, double annealed, (Charpy v-notch)	29 (RT)	25 (20°K)
L-605[8], soln treated, (Charpy v-notch)	55 (RT)	35 (20°K)

Table 4.32 Impact Energy of Nickel and Nickel Alloys in Foot-Pounds

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
Hastelloy B[8], sheet 20% cold reduced, (k_t=7.2)	155000 (RT)	210000 (20°K)
Hastelloy B[8], sheet, 40% cold reduced, (k_t=7.2)	230000 (RT)	300000 (20°K)
Hastelloy C[8], sheet, 20% cold reduced, (k_t=7.2)	182000 (RT)	245000 (20°K)
Hastelloy C[8], sheet, 20% cold reduced, aged, (k_t=7.2)	172000 (RT)	232000 (20°K)
Hastelloy C[8], sheet, soln treated, (k_t=7.2)	105000 (RT)	155000 (20°K)
Inconel 718[8], sheet, annealed and aged, (k_t=7), longitudinal	205000 (RT)	255000 (20°K)
Inconel 718[8], sheet, annealed and aged, (k_t=7), transverse	205000 (RT)	250000 (20°K)
Inconel 718[8], sheet, cold reduced, aged, (k_t=7.2)	250000 (RT)	300000 (20°K)
Inconel X[8], sheet, soln treated, aged, (k_t=7)	172000 (RT)	200000 (20°K)
K-Monel[8], sheet, soln treated, aged (k_t=10)	90000 (RT)	130000 (20°K)
René 41[8], sheet, soln treated, (k_t=7.2)	168000 (RT)	219000 (20°K)
René 41[8], sheet, soln treated, (k_t=10)	180000 (RT)	197000 (20°K)
René 41[8], sheet, soln treated, (k_t=21)	147000 (RT)	172000 (20°K)

Table 4.33 Notched Tensile Strength of Nickel and Nickel Alloys in PSI

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
AL-718[6], forging annealed, (k_t=6.3)	271000 (RT)	308000 (20°K)
AL-718[6], strip cold rolled, (k_t=6.5)	NO DATA	316000 (20°K)
AL-718[6], strip, cold rolled, aged, (k_t=6.3)	182000 (RT)	236000 (77.6°K)
D-979[8], sheet, annealed, (k_t=3.5)	146000 (RT)	200000 (20°K)
D-979[8], sheet, annealed, (k_t=8)	130000 (RT)	169000 (20°K)
L-605[8], sheet, annealed, (k_t=8)	115000 (RT)	200000 (20°K)
L-605[8], sheet, 20% cold reduced, (k_t=7.2)	170000 (RT)	270000 (20°K)
L-605[8], sheet, 40% cold reduced, (k_t=7.2)	240000 (RT)	280000 (20°K)
R-235[8], sheet, soln treated, (k_t=7.2)	97000 (RT)	140000 (20°K)

Table 4.33 Notched Tensile Strength of Nickel and Nickel Alloys in PSI (cont.)

MATERIAL	Impact Energy (upper temp)	Impact Energy (lowest temp)
CONSTRUCTION STEEL		
AISI/SAE 1043[21], plate, (unnotched)	145 (RT)	0 (77°K)
AISI/SAE 2330[7], quenched, tempered, (Charpy k-notch)	36 (RT)	17 (20°K)
AISI/SAE 2330[7], normalized, (Charpy k-notch)	18 (RT)	3 (20°K)
AISI/SAE 2800[8], double normalized, stress relieved, (Charpy v-notch)	112 (RT)	30 (20°K)
AISI/SAE 4340[8], quenched, tempered, (Charpy v-notch)	12 (RT)	5 (20°K)
AISI/SAE 8630[7], normalized, (Charpy, k-notch)	29 (RT)	3 (20°K)
AISI/SAE 8630[7], quenched, tempered, (Charpy k-notch)	39 (RT)	5 (20°K)
9% Ni Steel[7], double normalized, stress relieved, (Charpy k-notch)	48 (RT)	21 (20°K)
9% Ni Steel[11], double normalized, tempered, (Charpy v-notch)	100 (RT)	25 (20°K)
9% Ni Steel[11], quenched tempered, (Charpy v-notch	99 (RT)	36 (20°K)
18% Ni Maraging Steel[8], soln treated, aged, (Charpy v-notch)	23 (RT)	17 (20°K)

Table 4.34 Impact Energy of Ferrous Materials in Foot-Pounds

MATERIAL	Impact Energy (upper temp)	Impact Energy (lowest temp)
INVAR(8), bar, cold reduced, (Charpy k-notch)	26 (RT)	20 (20°K)
STAINLESS STEEL-AUSTENITIC		
AISI 303(8), bar, cold reduced, (Charpy k-notch)	50 (RT)	42 (20°K)
AISI 304(7), annealed, (Charpy k-notch)	78 (RT)	80 (20°K)
AISI 304(7), cold drawn to 210000 UTS, (Charpy k-notch)	26 (RT)	26 (20°K)
AISI 304(8), bar, cold drawn to 211000 UTS, (Charpy k-notch)	25 (RT)	25 (20°K)
AISI 304(6), plate, (Charpy v-notch)	110 (RT)	90 (20°K)
AISI 310(6), plate, (Charpy v-notch)	100 (RT)	80 (20°K)
AISI 316(6), plate, (Charpy v-notch)	110 (RT)	90 (20°K)
CAST STAINLESS STEEL		
CF-8, annealed (Charpy k-notch)	75 (RT)	52 (20°K)

Table 4.34 Impact Energy of Ferrous Materials in Foot-Pounds (cont.)

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
CONSTRUCTION STEEL		
18% Ni Maraging Steel(8), soln treated, (k_t=7.2)	180000 (RT)	330000 (20°K)
18% Ni Maraging Steel(8), soln treated, (k_t=21)	210000 (RT)	130000 (20°K)
18% Ni Maraging Steel(8), soln treated, aged, (k_t=7.2)	330000 (RT)	260000 (20°K)
STAINLESS STEEL-AUSTENITIC		
AISI 301(8), sheet, 3/4 hard, (k_t=7.2), longitudinal	200000 (RT)	248000 (20°K)
AISI 301(8), sheet, 3/4 hard, (k_t=7.2), transverse	187500 (RT)	152500 (20°K)
AISI 301(8), extra full hard, (k_t=7.2)	240000 (RT)	310000 (20°K)
AISI 304(8), sheet, extra low carbon, full hard, (k_t=3.8), longitudinal	190000 (RT)	315000 (20°K)
AISI 304(8), sheet, extra low carbon, full hard, (k_t=3.8), transverse	220000 (RT)	365000 (20°K)
AISI 304(8), sheet, extra low carbon, full hard, (k_t=7.2), longitudinal	200000 (RT)	315000 (20°K)
AISI 304(8), sheet, extra low carbon, full hard, (k_t=7.2), transverse	220000 (RT)	335000 (20°K)

Table 4.35 Notched Tensile Strength of Ferrous Materials in PSI

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
AISI 304[8], sheet, extra low carbon, full hard, (k_t=21), longitudinal	170000 (RT)	240000 (20°K)
AISI 304[8], sheet, extra low carbon, full hard, (k_t=21), transverse	144000 (RT)	208000 (20°K)
AISI 304L[6], strip cold rolled, full hard, (k_t=6.3)	192000 (RT)	302000 (20°K)
AISI 310[8], sheet, 75% cold reduced, (k_t=3.8), longitudinal	200000 (RT)	340000 (20°K)
AISI 310[8], sheet, 75% cold reduced, (k_t=3.8), transverse	215000 (RT)	385000 (20°K)
AISI 310[8], sheet, 75% cold reduced, (k_t=7.2), longitudinal	200000 (RT)	330000 (20°K)
AISI 310[8], sheet, 75% cold reduced, (k_t=7.2), transverse	200000 (RT)	330000 (20°K)
AISI 310[8], sheet, 75% cold reduced, (k_t=21), longitudinal	160000 (RT)	210000 (20°K)
AISI 310[8], sheet, 75% cold reduced, (k_t=21), transverse	120000 (RT)	190000 (20°K)
AISI 310[6], strip, cold rolled, extra hard, (k_t=6.3)	197000 (RT)	312000 (20°K)

Table 4.35 Notched Tensile Strength of Ferrous Materials in PSI (cont.)

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
AISI 347[8], plate, annealed, (k_t=6.3)	105000 (RT)	195000 (4.2°K)
A-286[8], soln treated, (k_t=3.5)	185000 (RT)	255000 (20°K)
A-286[8], soln treated, (k_t=7.2)	135000 (RT)	200000 (20°K)
A-286[8], soln treated, (k_t=10)	80000 (RT)	130000 (20°K)
AM-350[8], sub-zero cooled, tempered, (k_t=6.6)	80000 (RT)	210000 (20°K)
AM-355[8], sheet, cold rolled, tempered, (k_t=7.2), longitudinal	255000 (RT)	125000 (20°K)
AM-355[8], sheet, cold rolled, tempered, (k_t=7.2), transverse	230000 (RT)	125000 (20°K)

Table 4.35 Notched Tensile Strength of Ferrous Materials in PSI (cont.)

MATERIAL	Impact Energy (upper temp)	Impact Energy (lowest temp)
TITANIUM-ALPHA		
Commercially Pure Ti[7], annealed, (Charpy k-notch)	14 (RT)	4 (20°K)
Commercially Pure Ti[8], annealed, 40000 PSI yield, longitudinal, (Charpy v-notch)	60 (RT)	12 (20°K)
Commercially Pure Ti[8], annealed, 40000 PSI yield, transverse, (Charpy v-notch)	46 (RT)	14 (20°K)
Ti-5Al-2.5Sn[8], normal interstitial, annealed, (Charpy v-notch)	23 (RT)	8 (20°K)
TITANIUM-ALPHA-BETA		
Ti-4Al-4Mn[7], annealed, (Charpy k-notch)	10 (RT)	3 (20°K)
Ti-6Al-4V[8], soln treated, aged, (Charpy v-notch)	17 (RT)	12 (20°K)
Ti-6Al-4V[8], normal interstitial, annealed, (Charpy v-notch)	22 (RT)	8 (20°K)
Ti-6Al-4V[8], extra low interstitial, annealed, (Charpy v-notch)	18 (RT)	12 (20°K)
TITANIUM-BETA		
Ti-13V-11Cr-3Al[8], soln treated, (Charpy v-notch)	5 (RT)	3 (20°K)

Table 4.36 Impact Energy of Titanium and Titanium Alloys in Foot-Pounds

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
TITANIUM-ALPHA		
Commercially Pure Ti[8] annealed, (k_t=6.3)	150000 (RT)	235000 (20°K)
Commercially Pure Ti[8] annealed, (k_t=7.2)	100000 (RT)	160000 (20°K)
Commercially Pure Ti[8] annealed, (k_t=13.6)	75000 (RT)	125000 (20°K)
Ti-5Al-2.5Sn[5], sheet, annealed, (k_t=3)	175000 (RT)	295000 (20°K)
Ti-5Al-2.5Sn[8], sheet, annealed, extra low interstitial, (k_t=7.2)	150000 (RT)	230000 (20°K)
Ti-5Al-2.5Sn[8], sheet, annealed, extra low interstitial, (k_t=21)	115000 (RT)	120000 (20°K)
Ti-5Al-2.5Sn[8], sheet, annealed, normal interstitial, (k_t=3.5)	160000 (RT)	270000 (20°K)
Ti-5Al-2.5Sn[8], sheet, annealed, normal interstitial, (k_t=7.2)	150000 (RT)	180000 (20°K)
Ti-5Al-2.5Sn[8], sheet, annealed, normal interstitial, (k_t=21)	125000 (RT)	110000 (20°K)
Ti-7Al-12Zr[8], sheet, (k_t=7.2), longitudinal	175000 (RT)	140000 (20°K)
Ti-7Al-12Zr[8], sheet, (k_t=7.2), transverse	180000 (RT)	155000 (20°K)
Ti-8Al-1Mo-1V[8], sheet, annealed, (k_t=3.5)	175000 (RT)	280000 (20°K)
Ti-8Al-1Mo-1V[8], sheet, annealed, (k_t=7.2)	155000 (RT)	180000 (20°K)

Table 4.37 Notched Tensile Strength of Titanium and Titanium Alloys in PSI

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
Ti-8Al-1Mo-1V[8], sheet, annealed, (k_t=8)	150000 (RT)	140000 (20°K)
Ti-8Al-1Mo-1V[8], sheet, annealed, (k_t=10)	145000 (RT)	140000 (20°K)
Ti-8Al-1Mo-1V[8], sheet, duplex annealed, (k_t=3.5)	170000 (RT)	250000 (20°K)
Ti-8Al-1Mo-1V[8], sheet, duplex annealed, (k_t=8)	160000 (RT)	160000 (20°K)
Ti-8Al-2Cb-1Ta[8], sheet, annealed, (k_t=7.2), longitudinal	151000 (RT)	207000 (20°K)
Ti-8Al-2Cb-1Ta[8], sheet, annealed, (k_t=7.2), transverse	151000 (RT)	192000 (20°K)
TITANIUM-ALPHA-BETA		
Ti-6Al-4V[5], sheet, annealed, (k_t=3)	162000 (RT)	300000 (20°K)
Ti-6Al-4V[8], sheet, extra low interstitial, annealed, (k_t=3.5)	170000 (RT)	300000 (20°K)
Ti-6Al-4V[8], sheet, extra low interstitial, annealed, (k_t=7.2)	165000 (RT)	190000 (20°K)
Ti-6Al-4V[8], sheet, extra low interstitial, annealed, (k_t=8)	160000 (RT)	175000 (20°K)
Ti-6Al-4V[8], sheet, extra low interstitial, annealed, (k_t=21)	135000 (RT)	110000 (20°K)
TITANIUM-BETA		
Ti-13V-11Cr-3Al[8], sheet, soln treated, (k_t=3)	195000 (RT)	100000 (20°K)

Table 4.37 Notched Tensile Strength of Titanium and Titanium Alloys in PSI (cont.)

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
Ti-13V-11Cr-3Al[8], sheet, soln treated, (k_t=7.2)	165000 (RT)	130000 (20°K)
Ti-13V-11Cr-3Al[8], sheet, soln treated, (k_t=10)	155000 (RT)	90000 (20°K)

Table 4.37 Notched Tensile Strength of Titanium and Titanium Alloys in PSI (cont.)

MATERIAL	Impact Energy (upper temp)	Impact Energy (lowest temp)
MAGNESIUM AND MAGNESIUM ALLOYS		
Commercially Pure Magnesium[7], extruded, (Charpy k-notch)	3 (RT)	3.5 (20°K)
Commercially Pure Magnesium[7], cast, (Charpy k-notch)	3 (RT)	3 (20°K)
AZ31B-0[7,20], (Charpy v-notch)	5.9 (RT)	3 (20°K)
AZ31B[7], extruded, (Charpy k-notch)	4 (RT)	4 (20°K)
HM21A-T8[7,20], (Charpy v-notch)	1.5 (RT)	1.25 (20°K)
HK31A-01[7,20], (Charpy v-notch)	4 (RT)	3.3 (20°K)
ZK60A-T5[7], extruded (Charpy v-notch)	5 (RT)	3 (20°K)
ZE10A-H10[7,20], (Charpy v-notch)	7 (RT)	4.7 (20°K)
HM31A-F[20], (Charpy v-notch)	4.6 (RT)	4.3 (77°K)
OTHER METALS		
Commercially Pure Lead (Charpy k-notch)	12 (RT)	24 (20°K)

Table 4.38 Impact Energy of Miscellaneous Metals in Foot-Pounds

MATERIAL	Notched Tensile Strength (upper temp)	Notched Tensile Strength (lowest temp)
Tantalum[5], bar, wrought, stress relieved, (k_t=3)	95000 (RT)	293000 (20°K)
Tantalum[5], bar, recrystallized, (k_t=3)	54000 (RT)	197000 (20°K)
Columbium[5], bar, wrought, stress relieved, (k_t=3)	67000 (RT)	258000 (20°K)
Columbium[5], bar, recrystallized, (k_t=3)	46000 (RT)	136000 (20°K)

Table 4.39 Notched Tensile Strength of Miscellaneous Metals in PSI

MATERIAL	Impact Energy (upper temp)	Impact Energy (lowest temp)
COMPOSITE MATERIALS		
TFE Teflon[8], sheet, 15% graphite filled, (Izod)	2.2 (RT)	1 (20°K)
TFE Teflon[8], sheet, 65% bronze filled, (Izod)	2 (RT)	1.25 (20°K)
TFE Teflon[8], sheet, 25% asbestos filled, (Izod)	1.5 (RT)	0.8 (20°K)
FEP Teflon[8], sheet, 116 glass cloth reinf., through fabric, (Izod)	38 (RT)	25 (20°K)
FEP Teflon[8], sheet 116 glass cloth reinf., with fabric, (Izod)	29 (RT)	18 (20°K)
TFE Teflon[8], sheet, 128 glass cloth reinf., through fabric, (Izod)	12 (RT)	11 (20°K)
TFE Teflon[8], sheet, 128 glass cloth reinf., with fabric, (Izod)	1.5 (RT)	0.5 (20°K)
POLYMERS		
Nylon[8], Type 101, sheet, (Izod)	0.5 (RT)	0.6 (20°K)
TFE Teflon[8], sheet, 52.5-71% crystallinity, (Izod)	2 (RT)	1.7 (20°K)
KEL-F[8], sheet, 60-70% crystallinity, (Izod)	1.25 (RT)	1.4 (20°K)

Table 4.40 Impact Energy of Composite Materials and Polymers in Foot-Pounds per Inch of Notch

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
1100-H16[8], bar, flexure, (17.5 ksi UTS), R=-1	10000, 4×10^6 (RT)	25000, 9.5×10^3 (RT)	22000, 3×10^6 (77.6°K)	47000, 4×10^3 (77.6°K)
2014-T6[8], sheet, axial, R=-1	15000, 5×10^6 (RT)	53000, 2×10^3 (RT)	46000, 3×10^6 (20°K)	78000, 9×10^2 (20°K)
2020-T6[8], sheet, axial, (82.6 ksi UTS), R=-1	18000, 10^7 (RT)	60000, 6×10^2 (RT)	40000, 10^7 (20°K)	75000, 1.5×10^3 (20°K)
2024-T4[8], bar, flexure, (69.6 ksi UTS), R=-1	22000, 6×10^7 (RT)	77000, 1.5×10^3 (RT)	47000, 4×10^6 (77.6°K)	100000, 10^3 (77.6°K)
2219-T62[8], sheet, axial, R=-1	18000, 6×10^6 (RT)	40000, 10^3 (RT)	36000, 2×10^6 (20°K)	67000, 6×10^2 (20°K)
5083-H113[8], plate, flexure, R=-1	17000, 10^8 (RT)	26000, 10^5 (RT)	23000, 10^7 (89°K)	35000, 10^5 (89°K)
5456-H343[8], sheet, axial, (56.5 ksi UTS), R=-1	15000, 10^7 (RT)	45000, 6×10^2 (RT)	40000, 10^7 (20°K)	60000, 3×10^3 (20°K)

Table 4.41 Fatigue Strength in PSI of Aluminum and Aluminum Alloys and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
6061-T6[8], bar, flexure, (44.2 ksi UTS), R=-1	20000, 10^8 (RT)	60000, 2×10^3 (RT)	40000, 6×10^6 (77.6°K)	80000, 4×10^3 (77.6°K)
7039-T6[8], sheet, axial, R=-1	32000, 3.2×10^6 (RT)	73000, 6×10^2 (RT)	57000, 3.2×10^6 (20°K)	98000, 4×10^2 (20°K)
7075-T6[8], sheet, axial, (78.8 ksi UTS), R=-1	12000, 10^7 (RT)	66000, 10^3 (RT)	35000, 10^7 (20°K)	80000, 10^3 (20°K)

Table 4.41 Fatigue Strength in PSI of Aluminum and Aluminum Alloys and Corresponding Life Cycles (cont.)

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
2014-T6[8], sheet, axial, R=-1, (k_t=3.5)	8000, 2×10^6 (RT)	36000, 6×10^2 (RT)	7000, 2×10^6 (20°K)	46000, 4×10^2 (20°K)
2014-T6[8], sheet, axial, R=-1, (k_t=8)	5000, 3×10^6 (RT)	28000, 2×10^3 (RT)	7000, 4×10^6 (20°K)	33000, 0.5×10^3 (20°K)
2219-T62[8], sheet, axial, R=-1, (k_t=3.5)	5000, 3×10^6 (RT)	45000, 8×10^2 (RT)	8000, 2×10^6 (20°K)	33000, 10^3 (20°K)
2219-T87[8], sheet, axial, (66.7 ksi UTS) R=-1, (k_t=3.5)	7000, 10^7 (RT)	32000, 5×10^3 (RT)	8000, 2×10^6 (20°K)	39000, 6×10^2 (20°K)
7039-T6[8], sheet, axial, R=-1, (k_t=8)	5000, 2×10^6 (RT)	33000, 9×10^2 (RT)	11000, 2×10^6 (20°K)	37000, 4×10^2 (20°K)
7075-T6[8], sheet, axial, (78.8 ksi UTS) R=-1, (k_t=3.5)	8000, 8×10^6 (RT)	31000, 10^3 (RT)	11000, 2×10^6 (20°K)	38000, 7×10^2 (20°K)
7075-T6[8], bar, flexure, (83.9 ksi UTS) R=-1, (k_t=3.2)	15000, 10^7 (RT)	50000, 4×10^3 (RT)	27000, 10^6 (20°K)	53000, 8×10^2 (20°K)

Table 4.42 Notch Fatigue Strength in PSI of Aluminum and Aluminum Alloys and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
PURE COPPER				
ETP Copper[8], rod, axial, annealed, R=-1	31000, 1.5×10^6 (RT)	36000, 10^4 (RT)	42500, 1.5×10^6 (4.2°K)	45000, 4×10^4 (4.2°K)
COPPER-ZINC ALLOYS (BRASS)				
70/30 Brass[8], sheet, flexure, cold rolled, stress relieved, R=1	25000, 10^7 (RT)	90000, 3×10^4 (RT)	100000, 10^6 (20°K)	175000, 10^5 (20°K)
COPPER-BERYLLIUM ALLOYS				
Beryllium Copper[8] sheet, flexure, condition AT, (178 ksi UTS), R=-1	45000, 2×10^7 (RT)	135000, 1.2×10^4 (RT)	110000, 10^6 (20°K)	150000, 1.2×10^5 (20°K)
Beryllium Copper[8] sheet, flexure, condition 1/2 hard, (191 ksi UTS), R=-1	50000, 10^7 (RT)	105000, 2×10^4 (RT)	90000, 10^6 (20°K)	160000, 2×10^4 (20°K)

Table 4.43 Fatigue Strength in PSI of Copper and Copper Alloys and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
COPPER-ZINC ALLOYS (BRASS)				
70/30 Brass[8], sheet, flexure, cold rolled, stress relieved, R=1, (k_t=3.2)	20000, 7×10^6 (RT)	75000, 7×10^3 (RT)	50000, 10^6 (20°K)	100000, 3×10^4 (20°K)
70/30 Brass[8], sheet, flexure, cold rolled, stress relieved, R=1, (k_t=6.4)	20000, 3×10^6 (RT)	65000, 10^4 (RT)	50000, 10^6 (20°K)	95000, 4×10^4 (20°K)
COPPER-BERYLLIUM ALLOYS				
Beryllium Copper[8], sheet, flexure, condition AT, (170 ksi UTS), R=-1, (k_t=3.2)	20000, 1.2×10^7 (RT)	105000, 8×10^3 (RT)	45000, 1.2×10^6 (20°K)	105000, 4×10^4 (20°K)
Beryllium Copper[8], sheet, flexure, condition 1/2 hard, (191 ksi UTS), R=-1, (k_t=3.1)	27000, 10^7 (RT)	80000, 4×10^3 (RT)	50000, 10^6 (20°K)	85000, 1.2×10^4 (20°K)

Table 4.44 Notch Fatigue Strength in PSI of Copper and Copper Alloys and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
Beryllium Copper[8], sheet, flexure, condition 1/2 hard, (191 ksi UTS), R=-1, (k_t=6.6)	25000, 4×10^6 (RT)	80000, 2×10^3 (RT)	30000, 10^6 (20°K)	85000, 6×10^4 (20°K)

Table 4.44 Notch Fatigue Strength in PSI of Copper and Copper Alloys and Corresponding Life Cycles (cont.)

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
Pure Nickel A(8), sheet, flexure, annealed, R=-1	40000, 3×10^6 (RT)	85000, 9×10^4 (RT)	80000, 10^6 (20°K)	135000, 6×10^4 (20°K)
Hastelloy C(8), sheet, axial, soln treated, R=-1	45000, 4×10^6 (RT)	80000, 6×10^2 (RT)	90000, 2×10^6 (20°K)	113000, 4×10^2 (20°K)
Inconel(8), sheet, flexure, cold rolled, (132 ksi UTS), R=-1	45000, 10^7 (RT)	155000, 10^4 (RT)	100000, 8×10^5 (20°K)	180000, 2.5×10^4 (20°K)
Inconel X(8), sheet, flexure, soln treated, aged, R=-1	60000, 10^6 (RT)	185000, 6×10^3 (RT)	110000, 10^6 (20°K)	175000, 4×10^4 (20°K)
Inconel-718(8), sheet, axial, soln treated, R=-1	72000, 2×10^6 (RT)	98000, 3×10^2 (RT)	100000, 3×10^6 (20°K)	112000, 8×10^2 (20°K)
K-Monel(8), sheet, flexure, cold rolled, 1/2 hard, aged (182 ksi UTS), R=-1	35000, 1.2×10^7 (RT)	120000, 2×10^4 (RT)	100000, 10^6 (20°K)	150000, 4×10^4 (20°K)

Table 4.45 Fatigue Strength in PSI of Nickel and Nickel Alloys and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
Pure Nickel A[8], sheet, flexure, annealed, R=-1, (k_t=3.2)	15000, 1.2×10^7 (RT)	30000, 2×10^3 (RT)	35000, 1.1×10^6 (20°K)	50000, 4×10^3 (20°K)
Hastelloy C[8], sheet, axial, soln treated, R=-1, (k_t=3.8)	15000, 2×10^6 (RT)	70000, 2×10^3 (RT)	12000, 4×10^6 (20°K)	92000, 2×10^3 (20°K)
Inconel[8], sheet, flexure, cold rolled, (1132 ksi UTS) R=-1, (k_t=3.2)	30000, 7×10^6 (RT)	115000, 8×10^3 (RT)	50000, 10^6 (20°K)	120000, 5×10^4 (20°K)
Inconel X[8], sheet, flexure, soln treated, aged, R=-1, (k_t=3.2)	55000, 10^7 (RT)	100000, 4×10^4 (RT)	70000, 10^6 (20°K)	130000, 2×10^4 (20°K)
Inconel 718[8], sheet, axial, soln treated, R=-1, (k_t=3.5)	35000, 2.2×10^6 (RT)	79000, 1.5×10^3 (RT)	32000, 2×10^6 (20°K)	98000, 4×10^3 (20°K)
K-Monel[8], sheet flexure, cold rolled, 1/2 hard, aged, (182 ksi UTS) R=-1, (k_t=3.2)	10000, 10^7 (RT)	85000, 10^4 (RT)	30000, 1.5×10^6 (20°K)	100000, 4×10^4 (20°K)

Table 4.46 Notch Fatigue Strength in PSI of Nickel and Nickel Alloys and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
Narmco 513 Resin[8], 181 glass cloth reinforced, axial, R=.05	12000, 10^6 (RT)	28000, 10^3 (RT)	23000, 4×10^5 (77.6°K)	57000, 4×10^2 (77.6°K)
Trevarno F130 Resin[8], 181 glass cloth reinforced, axial, R=.05	11000, 10^6	21000, 2×10^3	24000, 10^6	52000, 4×10^2

Table 4.46 Fatigue Strength in PSI of Composite Materials and Corresponding Life Cycles (cont.)

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
CONSTRUCTION STEELS				
AISI/SAE 1075[8], sheet, flexure, hardened, tempered, R=-1	50000, 10^7 (RT)	240000, 4×10^3 (RT)	105000, 10^6 (20°K)	190000, 7×10^3 (20°K)
2800 (9% Ni)[8], sheet, flexure, double normalized, stress relieved, (128 ksi UTS), R=-1	70000, 10^6 (RT)	130000, 2×10^4 (RT)	115000, 10^6 (20°K)	175000, 1.5×10^4 (20°K)
STAINLESS STEEL-AUSTENITIC				
AISI 321[8], sheet, axial, annealed, R=-1	30000, 2×10^6 (RT)	52000, 5×10^2 (RT)	50000, 2×10^6 (20°K)	125000, 8×10^2 (20°K)
AISI 347[8], sheet, flexure, annealed, R=-1	17000, 10^6 (RT)	95000, 2×10^4 (RT)	95000, 9×10^5 (20°K)	170000, 4×10^4 (20°K)
A-286[8], sheet, axial, soln treated, R=-1	35000, 3×10^6 (RT)	53000, 7×10^2 (RT)	64000, 2×10^6 (20°K)	92000, 6×10^2 (20°K)
17-7PH-TH1050[8], sheet, flexure, (196 ksi UTS), R=-1	85000, 10^7 (RT)	150000, 2×10^4 (RT)	110000, 10^6 (20°K)	155000, 10^4 (20°K)

Table 4.47 Fatigue Strength in PSI of Ferrous Materials and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
CONSTRUCTION STEELS				
AISI/SAE 1075[8], sheet, flexure, hardened, tempered, R=-1, (k_t=3.2)	30000, 10^6 (RT)	80000, 1.5×10^4 (RT)	30000, 10^6 (20°K)	60000, 2×10^3 (20°K)
2800 (9% Ni)[8], sheet, flexure, double normalized, stress relieved, (128 ksi UTS), R=-1, (k_t=3.1)	30000, 2×10^7 (RT)	80000, 2×10^4 (RT)	45000, 4×10^5 (20°K)	75000, 10^4 (20°K)
STAINLESS STEEL-AUSTENITIC				
AISI 301[8], sheet, flexure, extra full hard, (241 ksi UTS), R=-1, (k_t=3.1)	25000, 10^7 (RT)	95000, 3×10^4 (RT)	60000, 7×10^4 (20°K)	140000, 4×10^3 (20°K)
AISI 304[8], bar, flexure, cold reduced, (212 ksi UTS), R=-1, (k_t=2.75)	20000, 10^7 (RT)	130000, 5×10^3 (RT)	55000, 10^6 (20°K)	60000, 4×10^4 (20°K)
AISI 321[8], sheet, axial, annealed, R=-1, (k_t=3.5)	15000, 1.5×10^6 (RT)	42000, 7×10^2 (RT)	27000, 1.5×10^6 (20°K)	90000, 6×10^2 (20°K)

Table 4.48 Notch Fatigue Strength in PSI of Ferrous Materials and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
AISI 347[8], sheet, flexure, annealed, R=-1, (k_t=3.2)	25000, 8×10^6 (RT)	52000, 10^4 (RT)	70000, 10^6 (20°K)	95000, 3×10^4 (20°K)
A-286[8], sheet, axial, soln treated, R=-1, (k_t=3.5)	21000, 3×10^6 (RT)	50000, 6×10^2 (RT)	16000, 2×10^6 (20°K)	90000, 2×10^3 (20°K)

Table 4.48 Notch Fatigue Strength in PSI of Ferrous Materials and Corresponding Life Cycles (cont.)

MATERIAL	Low F_n, n (uppper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
TITANIUM-ALPHA				
Ti-5Al-2.5Sn[8], sheet, axial, low interstitial, annealed, (116 ksi UTS), R=.01	75000, 10^6 (RT)	125000, 6×10^2 (RT)	130000, 6×10^6 (20°K)	225000, 2×10^2 (20°K)
TITANIUM-ALPHA-BETA				
Ti-6Al-4V[8], sheet, flexure, annealed, (136 ksi UTS), R=-1	45000, 10^7 (RT)	115000, 6×10^3 (RT)	80000, 10^6 (20°K)	145000, 2×10^4 (20°K)
Ti-6Al-4V[8], sheet, axial, low interstitial, soln treated, aged, (165 ksi UTS), R=-1	70000, 5×10^6 (RT)	170000, 3×10^3 (RT)	130000, 9×10^5 (20°K)	190000, 10^4 (20°K)
TITANIUM-BETA				
Ti-13V-11Cr-3Al[8], sheet, axial, soln treated, aged, (200 ksi UTS), R=.01	80000, 6×10^6 (RT)	185000, 6×10^3 (RT)	105000, 3×10^6 (20°K)	180000, 1.5×10^3 (20°K)

Table 4.49 Fatigue Strength in PSI of Titanium Alloys and Other Metals and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
OTHER METALS				
Ni-SPAN-C[8], sheet, flexure, soln treated, aged, (152 ksi UTS), R=-1	65000, 10^7 (RT)	115000, 1.5×10^4 (RT)	130000, 10^6 (20°K)	150000, 6×10^4 (20°K)

Table 4.49 Fatigue Strength in PSI of Titanium Alloys and Other Metals and Corresponding Life Cycles (cont.)

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
TITANIUM-ALPHA-BETA				
Ti-6Al-4V[8], sheet, flexure, annealed, (136 ksi UTS), R=-1, (k_t=3.1)	25000, 1.1×10^6 (RT)	70000, 1.5×10^4 (RT)	35000, 10^6 (20°K)	100000, 10^4 (20°K)
Ti-6Al-4V[8], sheet, flexure, annealed, (136 ksi UTS), R=-1, (k_t=6.4)	20000, 3×10^6 (RT)	75000, 10^4 (RT)	30000, 10^6 (20°K)	80000, 3×10^4 (20°K)
OTHER METALS				
Ni-SPAN-C[8], sheet, flexure, soln treated, aged, (152 ksi UTS), R=-1, (k_t=3.1)	25000, 6×10^6 (RT)	100000, 2×10^4 (RT)	65000, 6×10^5 (20°K)	145000, 2×10^4 (20°K)

Table 4.50 Notch Fatigue Strength in PSI of Titanium Alloys and Other Metals and Corresponding Life Cycles

MATERIAL	Low F_n, n (upper temp)	High F_n, n (upper temp)	Low F_n, n (lowest temp)	High F_n, n (lowest temp)
Epon 828 Resin[8], 181 glass cloth reinforced, axial, R=.05	22000, 1.5×10^6 (RT)	35000, 4×10^3 (RT)	35000, 10^6 (20°K)	79000, 10^4 (20°K)
Narmco 506 Resin[8], 181 glass cloth reinforced, axial, R=.05	15000, 10^6 (RT)	33000, 10^3 (RT)	22000, 10^6 (20°K)	54000, 10^2 (20°K)
CTL 91LD Resin[8], 181 glass cloth reinforced, axial, R=.05	22000, 10^6 (RT)	47000, 3×10^2 (RT)	32000, 10^6 (20°K)	58000, 3×10^2 (20°K)
Paraplex P43 Resin[8], 181 glass cloth reinforced, axial, R=.05	13000, 4×10^5 (RT)	40000, 2×10^2 (RT)	24000, 5×10^5 (20°K)	48000, 6×10^2 (20°K)
Vibrin 135 Resin[8], 181 glass cloth reinforced, axial, R=.05	24000, 1.5×10^6 (RT)	40000, 1.5×10^3 (RT)	33000, 10^6 (20°K)	52000, 6×10^2 (20°K)
Laminac 4231 Resin[8], 181 glass cloth reinforced, axial, R=.05	12000, 10^6 (RT)	38000, 2×10^2 (RT)	22000, 10^6 (20°K)	42000, 4×10^2 (20°K)

Table 4.51 Fatigue Strength in PSI of Composite Materials and Corresponding Life Cycles

MATERIAL	ENDURANCE LIMIT (upper temp)	ENDURANCE LIMIT (lowest temp)
5054-H32[23], bar, axial, R=0	28000 (RT)	36000 (77.6°K)
5083-H113[23], bar, axial, R=0	35000 (RT)	40000 (77.6°K)
5086-H32[23], bar, axial, R=0	34000 (RT)	40000 (77.6°K)
5456-H321[23], bar, axial, R=0	35000 (RT)	40000 (77.6°K)

Table 4.52 Endurance Limit of Aluminum Alloys in PSI

MATERIAL	k (upper temp)	k (lowest temp)
1100-0[8]	122 (RT)	27 (4.2°K)
1100-F[8,9]	121 (RT)	28.5 (4.2°K)
2014-T6[8]	94 (RT)	28 (20°K)
2024-T4[8,9]	64 (205°K)	1.5 (4.2°K)
2219-T87[8]	68 (RT)	25 (47°K)
3003-F[8,9]	88.5 (116°K)	1.5 (4.2°K)
5052-0[8,9,13]	77 (211°K)	2.8 (4.2°K)
5083-0[8]	39 (122°K)	3 (4.2°K)
5086-F[8]	41 (122°K)	3 (4.2°K)
5154-0[8,9,13]	72 (122°K)	2.1 (4.2°K)
6063-T5[9,13]	117.8 (RT)	20.4 (4.2°K)
7039-T61[8,13]	87 (RT)	3.09 (4.2°K)
7075-T6[8]	73 (RT)	11 (4.2°K)

Table 4.53 Thermal Conductivity of Aluminum and Aluminum Alloys in BTU/HR-FT-°F

MATERIAL	k (upper temp)	k (lowest temp)
PURE COPPER		
ETP Copper[9]	240 (RT)	180 (4.2°K)
OFHC Copper[8]	220 (RT)	575 (20°K)
99.999% Pure Copper[8]	0.2 (RT)	6 (4.2°K)
COPPER-ZINC ALLOYS (BRASSES)		
98 Cu, 2 Zn[13]	150.3 (100°K)	28.9 (10°K)
95 Cu, 5 Zn[13]	98.3 (95°K)	17.3 (10°K)
Alpha Brass[13] 68Cu,32Zn	31.8 (90°K)	2.3 (4.2°K)
Leaded Brass[13] 60.03Cu,35.7Zn, 3.27Pb,1Sn	30 (120°K)	1.27 (4.2°K)
Silber Bronze[13] 46Cu,41Zn,13Ni	31.2 (20°K)	.64 (4.2°K)
COPPER-TIN ALLOYS (BRONZES)		
Phosphor Bronze[13] 93.3Cu,6.46Sn,.3P	14.5 (80°K)	0.98 (4.2°K)
COPPER-SILICON ALLOYS		
Silicon Bronze[13]	7.5 (90°K)	1.4 (17°K)
COPPER-NICKEL ALLOYS		
Constantan[13] 55Cu,45Ni	13.3 (RT)	5.5 (25°K)
MISCELLANEOUS COPPER ALLOYS		
95.5 Cu, 4.5 Au[13]	50 (95°K)	14 (20°K)
90.3 Cu, 9.7 Au[13]	26.6 (100°K)	13.9 (20°K)

Table 4.54 Thermal Conductivity of Copper and Copper Alloys in BTU/HR-FT-°F

MATERIAL	k (upper temp)	k (lowest temp)
98.94 Cu, 1.04 Pb[13]	242.8 (80°K)	161.9 (6°K)
Manganin[13] 85Cu,12Mn,3Ni	7.2 (80°K)	0.35 (5°K)

Table 4.54 Thermal Conductivity of Copper and Copper Alloys in BTU/HR-FT-°F (cont.)

MATERIAL	k (upper temp)	k (lowest temp)
PURE NICKEL		
99.999% Pure Nickel[8,9] annealed	50 (RT)	100 (4.2°K)
NICKEL ALLOYS		
Monel[9], annealed hot rolled	12 (RT)	0.52 (4.2°K)
Monel[9], hard drawn, cold rolled	12 (RT)	0.31 (4.2°K)
Inconel[8,9], annealed	9 (RT)	0.65 (4.2°K)
Inconel[9] hard drawn	5.5 (80°K)	0.17 (4.2°K)
Inconel X[8] soln treated, double aged	6.8 (RT)	0.1 (4.2°K)
Inconel 718[8]	6.3 (RT)	0.4 (4.2°K)
Hastelloy X[8]	6.4 (RT)	0.4 (4.2°K)

Table 4.55 Thermal Conductivity of Nickel and Nickel Alloys in BTU/HR-FT-°F

MATERIAL	k (upper temp)		k (lowest temp)	
IRON				
99.999% Pure Iron[9]	47	(RT)	42	(4.2°K)
CONSTRUCTION STEELS				
SAE 1020[13]	.038	(RT)	0.016	(26°K)
SAE 1095[16]	.1	(RT)	0.02	(20°K)
STAINLESS STEEL-MARTENSITIC				
AISI 410[8]	16	(RT)	2.5	(20°K)
STAINLESS STEEL-AUSTENITIC				
AISI 303[8]	5	(77.6°K)	0.25	(4.2°K)
AISI 304[8]	9	(RT)	0.2	(4.2°K)
AISI 347[8]	8.5	(RT)	0.2	(4.2°K)

Table 4.56 Thermal Conductivity of Ferrous Materials in BTU/HR-FT-°F

MATERIAL	k (upper temp)	k (lowest temp)
TITANIUM-ALPHA		
Ti-5Al-2.5Sn[8]	4.7 (RT)	0.4 (4.2°K)
99.99% Pure Ti[8]	13 (RT)	4 (4.2°K)
TITANIUM-ALPHA BETA		
Ti-6Al-4V[8]	4.3 (RT)	0.7 (20°K)

Table 4.57 Thermal Conductivity of Titanium and Titanium Alloys in BTU/HR-FT-°F

MATERIAL	k (upper temp)	k (lowest temp)
99.99% Pure Silver[9] annealed	240 (RT)	8000 (4.2°K)
99.99% Pure Gold[9] annealed	190 (RT)	960 (4.2°K)
98% Pure Zirconium	24 (40°K)	7 (4.2°K)
99.98% Pure Tantalum	35 (100°K)	8.7 (4.2°K)

Table 4.58 Thermal Conductivity of Miscellaneous Metals in BTU/HR-FT-°F

MATERIAL	k (upper temp)	k (lowest temp)
Epoxy Fiberglass[8] Laminate E787 Resin, S/901 glass roving	0.42 (RT)	0.05 (20°K)
Epoxy Fiberglass Laminate EPON 828 Resin, S/901 glass roving	0.1 (RT)	0.02 (20°K)

Table 4.59 Thermal Conductivity of Composite Materials in BTU/HR-FT-°F

MATERIAL	k (upper temp)		k (lowest temp)	
Teflon[9], extruded	0.14	(80°K)	0.03	(4.2°K)
Nylon[9], drawn, monofilament	0.055	(20°K)	0.007	(4.2°K)
Perspex[9], organic glass thermo-plastic	0.05	(24°K)	0.035	(4.2°K)
Mylar[8], 0.014 inch sheet	0.6	(RT)	0.3	(20°K)
Plexiglas[13]	0.0491	(72°K)	0.0329	(4.2°K)
Polyethylene[13]	0.0346	(10°K)	0.0104	(4.2°K)

Table 4.60 Thermal Conductivity of Polymers in BTU/HR-FT-°F

MATERIAL	k (upper temp)	k (lowest temp)
Glass - average of quartz, pyrex and borosilicate glasses	0.56 (RT)	0.06 (4.2°K)

Table 4.61 Thermal Conductivity of Glass in BTU/HR-FT-°F

MATERIAL	c_p (upper temp)	c_p (lowest temp)
Pure Aluminum[9,12]	0.2125 (RT)	0.065 (4.2°K)
Pure Copper[9,12]	0.0837 (RT)	0.022 (4.2°K)
Pure Nickel[9,12]	0.1055 (RT)	0.0012 (4.2°K)
Monel[12]	0.1029 (RT)	0.0014 (20°K)
α-Iron[9,12]	0.1035 (RT)	0.000095 (4.2°K)
γ-Iron[9,12]	0.118 (RT)	0.0012 (20°K)
18-8 Stainless Steel[12], 74 γ-iron, 18 Cr, 8 Ni	0.114 (RT)	0.0011 (20°K)
Pure Titanium[9]	0.11 (RT)	0.00008 (4.2°K)
Pure Magnesium[12]	0.235 (RT)	0.004 (20°K)
Pure Chromium[12]	0.1073 (RT)	0.0006 (20°K)
Teflon-Molded[9]	0.22 (RT)	0.0001 (5°K)
Polyethylene[9]	0.54 (RT)	0.088 (60°K)

Table 4.62 Constant Pressure Specific Heat of Various Materials in BTU/LBM°F

MATERIAL	α (upper temp)	α (lowest temp)
Pure Aluminum[8]	0 (RT)	-0.00415 (4.2°K)
1100-0[8]	0 (RT)	-0.00405 (20°K)
2014-T6[8]	0 (RT)	-0.0042 (20°K)
2020-T6[8]	0 (RT)	-0.0041 (20°K)
2024-T86[8]	0 (RT)	-0.0042 (20°K)
2219-T87[8]	0 (RT)	-0.0042 (20°K)
5456-H343[8]	0 (RT)	-0.0043 (20°K)
6061-T6[8]	0 (RT)	-0.00415 (20°K)
7039-T6[8]	0 (RT)	-0.0042 (20°K)
7075-T6[8]	0 (RT)	-0.0042 (20°K)
356-T6[8], permanent mold casting	0 (RT)	-0.0039 (20°K)
TENS-50[8]	0 (RT)	-0.0039 (20°K)

Table 4.63 Linear Thermal Expansion Coefficient of Aluminum and Aluminum Alloys in Inches per Inch

MATERIAL	α (upper temp)		α (lowest temp)	
Pure Copper[9]	0	(RT)	-0.00327	(4.2°)
Pure Copper[8] annealed	0	(RT)	-0.00325	(20°K)
70/30 Brass[8] 3/4 hard	0	(RT)	-0.00375	(20°K)
Yellow Brass[12] free machining	0.00397	(RT)	0	(0°K)
Beryllium Copper[8]	0	(RT)	-0.0031	(20°K)

Table 4.64 Linear Thermal Expansion Coefficient of Copper and Copper Alloys in Inches per Inch

MATERIAL	α (upper temp)	α (lowest temp)
Pure Nickel[9]	0 (RT)	-0.00225 (4.2°K)
Pure Nickel[8], annealed	0 (RT)	-0.0023 (20°K)
Monel[12]	0.00261 (RT)	0 (0°K)
Inconel[13]	0.00238 (RT)	0 (0°K)
Inconel[8], annealed	0 (RT)	-0.0023 (20°K)
Inconel X[8] soln treated, aged	0 (RT)	-0.0025 (20°K)
Inconel 718[8]	0 (RT)	-0.00235 (20°K)
K-Monel[8], soln treated, aged	0 (RT)	-0.0025 (20°K)
S-Monel[8], annealed	0 (RT)	-0.0025 (20°K)
Hastelloy B[8], annealed	0 (RT)	-0.0019 (20°K)
Rene 41[8], soln treated	0 (RT)	-0.0022 (20°K)
D-979[8], annealed	0 (RT)	-0.00235 (20°K)
L-605[8]	0 (RT)	-0.00215 (20°K)

Table 4.65 Linear Thermal Expansion Coefficient of Nickel and Nickel Alloys in Inches per Inch

MATERIAL	α (upper temp)		α (lowest temp)	
IRON				
Iron[9]	0	(RT)	-0.00198	(4.2°K)
CONSTRUCTION STEELS				
SAE 1020[12]	0.0021	(RT)	0	(0°K)
SAE 1075[8] quenched and tempered	0	(RT)	-0.00195	(20°K)
SAE 4340[8], annealed	0	(RT)	-0.00193	(20°K)
9% Nickel Steel[8] double normalized and tempered	0	(RT)	-0.0021	(20°K)
9% Nickel Steel[11] double normalized and stress relieved	0	(RT)	-0.0019	(4.2°K)
STAINLESS STEELS-MARTENSITIC				
AISI 410[8]	0	(RT)	-0.00175	(20°K)
AISI 416[8]	0	(RT)	-0.0018	(20°K)
AISI 440C[8]	0	(RT)	-0.0018	(20°K)
17-4PH-H1100[8]	0	(RT)	-0.0019	(20°K)
STAINLESS STEELS-AUSTENITIC				
AISI 302[8,11], cold drawn	0	(RT)	-0.0031	(20°K)
AISI 303[8], annealed	0	(RT)	-0.003	(20°K)
AISI 304[12]	0.00304	(RT)	0	(0°K)

Table 4.66 Linear Thermal Expansion Coefficient of Ferrous Materials in Inches per Inch

MATERIAL	α (upper temp)	α (lowest temp)
AISI 304[8,11] annealed	0 (RT)	-0.003 (20°K)
AISI 310[8], annealed	0 (RT)	-0.00285 (20°K)
AISI 321[8], annealed	0 (RT)	-.0029 (20°K)
AISI 347[8], annealed	0 (RT)	-0.003 (20°K)
A-286[8], soln treated, aged	0 (RT)	-0.0029 (20°K)
17-7PH-TH1050[8]	0 (RT)	-0.00225 (20°K)

Table 4.66 Linear Thermal Expansion Coefficient of Ferrous Materials in Inches per Inch (cont.)

MATERIAL	α (upper temp)		α (lowest temp)	
TITANIUM-ALPHA				
Ti-5Al-2.5Sn[8] normal interstitial, annealed	0	(RT)	-0.00175	(20°K)
Ti-8Al-1MO-1V[8] annealed	0	(RT)	-0.0016	(20°K)
Pure Titanium[12]	0.00155	(RT)	0	(0°K)
TITANIUM-ALPHA-BETA				
Ti-6Al-4V[8], normal interstitial, annealed	0	(RT)	-0.0017	(20°K)
TITANIUM-BETA				
Ti-13V-11Cr-3Al[8], soln treated	0	(RT)	-0.0016	(20°K)

Table 4.67 Linear Thermal Expansion Coefficient of Titanium and Titanium Alloys in Inches per Inch

MATERIAL	α (upper temp)		α (lowest temp)	
Pure Silver[7]	0	(RT)	-0.00413	(4.2°K)
Elgiloy[8], 45% cold reduction	0	(RT)	-0.00255	(20°K)
Ni-SPAN-C[8], soln treated, aged	0	(RT)	-0.0013	(20°K)
Pure Magnesium[12]	0.00503	(RT)	0	(0°K)
Pure Zinc[12]	0.00572	(RT)	0	(0°K)

Table 4.68 Linear Thermal Expansion Coefficient of Miscellaneous Metals in Inches per Inch

MATERIAL	α (upper temp)	α (lowest temp)
TFE Teflon, 65% bronze filled[8]	0 (RT)	-0.0145 (20°K)
TFE Teflon, 15% graphite filled[8]	0 (RT)	-0.0155 (20°K)
TFE Teflon, 25% asbestos filled[8]	0 (RT)	-0.0205 (20°K)
FEP Teflon, 20% glass filled[8]	0 (RT)	-0.009 (20°K)
TFE Teflon, 25% glass filled[8]	0 (RT)	-0.016 (20°K)
FEP Teflon, 116 glass cloth reinforced, with fabric[8]	0 (RT)	-0.0037 (20°K)
TFE Teflon, 128 glass cloth reinforced, with fabric[8]	0 (RT)	-0.0042 (20°K)
TFE Teflon, 128 glass cloth reinforced, through fabric[8]	0 (RT)	-0.0135 (20°K)
TFE Molded Teflon, chopped glass fibers, random orientation, normal to thickness[8]	0 (RT)	-0.065 (20°K)
TFE Molded Teflon, chopped glass fibers,[8] random orientation, with thickness	0 (RT)	-0.025 (20°K)
TFE Molded Teflon, 0.5 inch squares of graphite cloth,[8] random orientation, normal to thickness	0 (RT)	-0.08 (20°K)
TFE Molded Teflon, 0.5 inch squares of graphite cloth,[8] random orientation, with thickness	0 (RT)	-0.02 (20°K)
TFE Teflon, long fiber felted asbestos,[8] sheet reinforced, with warp	0 (RT)	-0.002 (20°K)
TFE Teflon, long fiber felted asbestos,[8] sheet reinforced, with weave	0 (RT)	-0.0035 (20°K)

Table 4.69 Linear Thermal Expansion Coefficient of Composite Materials in Inches per Inch

MATERIAL	α (upper temp)	α (lowest temp)
TFE Teflon, long fiber felted asbestos,[8] sheet reinforced, with thickness	0 (RT)	-0.03 (20°K)
E-787 Resin, S/901 roving bidirectional filament[8] reinforced, parallel to reinf.	0 (RT)	-0.0016 (20°K)
E-787 Resin, S/901 roving bidirectional filament[8] reinforced, perpendicular to reinf.	0 (RT)	-0.00145 (20°K)
E-787 Resin, S/901 roving unidirectional filament[8] reinforced, parallel to reinf.	0 (RT)	-0.0007 (20°K)
E-787 Resin, S/901 roving unidirectional filament[8] reinforced, perpendicular to reinf.	0 (RT)	-0.0056 (20°K)
E-787 Resin, S/901 1543 cloth reinforced[8] parallel to reinf.	0 (RT)	-0.0012 (20°K)
E-787 Resin, S/901 1543 cloth reinforced[8] perpendicular to reinf.	0 (RT)	-0.0041 (20°K)
E-787 Resin, S/901 1581 cloth reinforced[8] parallel to reinf.	0 (RT)	-0.0023 (20°K)
E-787 Resin, S/901 1581 cloth reinforced[8] perpendicular to reinf.	0 (RT)	-0.0025 (20°K)
E-787 Resin, S-994/HTS unidirectional filament[8] glass roving, normal to thickness	0 (RT)	-0.0007 (20°K)

Table 4.69 Linear Thermal Expansion Coefficient of Composite Materials in Inches per Inch (cont.)

MATERIAL	α (upper temp)	α (lowest temp)
E-787 Resin, S-994/HTS unidirectional filament[8] glass roving, with thickness	0 (RT)	-0.0034 (20°K)
Epon 828 Resin, potassium titanate fiber[8] random orientation, normal to thickness	0 (RT)	-0.0042 (20°K)
Epon 828 Resin, potassium titanate fiber[8] random orientation, with thickness	0 (RT)	-0.0077 (20°K)
Epon 828 Resin, phenolic micro-balloons (BJ00930),[8] random orientation, normal to thickness	0 (RT)	-0.0085 (20°K)
Epon 828 Resin, phenolic micro-balloons (BJ00930),[8] random orientation, with thickness	0 (RT)	-0.0088 (20°K)
Epon 828 Resin, perlite granules (LM-30),[8] random orientation, normal to thickness	0 (RT)	-0.003 (20°K)
Epon 828 Resin, perlite granules (LM-30),[8] random orientation, with thickness	0 (RT)	-0.003 (20°K)
Epon 828 Resin, glass micro-balloons (eccospheres R),[8] normal to thickness	0 (RT)	-0.0046 (20°K)
Epon 828 Resin, glass micro-balloons (eccospheres R)[8] with thickness	0 (RT)	-0.0049 (20°K)
CTL-91LD Resin, E/VOLAN A, 181 glass cloth reinforced[8] with warp	0 (RT)	-0.0015 (20°K)
CTL-91LD Resin, E/VOLAN A, 181 glass cloth reinforced[8] with weave	0 (RT)	-0.0016 (20°K)

Table 4.69 Linear Thermal Expansion Coefficient of Composite Materials in Inches per Inch (cont.)

MATERIAL	α (upper temp)	α (lowest temp)
CTL-91LD Resin, E/VOLAN A, 181 glass cloth reinforced[8] with thickness	0 (RT)	-0.0041 (20°K)
SC-1008 Resin, WCB graphite cloth reinforced[8] with warp	0 (RT)	-0.001 (20°K)
SC-1008 Resin, WCB graphite cloth reinforced[8] with weave	0 (RT)	-0.0014 (20'K)
SC-1008 Resin, WCB graphite cloth reinforced[8] with thickness	0 (RT)	-0.0042 (20°K)
CTL-91LD Resin, SN-19 Nylon-YN-25 cloth in 0.5 inch[8] squares, random orientation, normal to thickness	0 (RT)	-0.0083 (20°K)
CTL-91LD Resin, SN-19 Nylon-YN-25 cloth in 0.5 inch[8] squares, random orientation, with thickness	0 (RT)	-0.017 (20°K)
Selectron 5158 Resin, S/901 roving bidirectional[8] filament, parallel to reinf.	0 (RT)	-0.0011 (20°K)
Selectron 5158 Resin, S/901 roving bidirectional[8] filament, perpendicular to reinf.	0 (RT)	-0.0012 (20°K)
Paraplex P-43/Benzoyl Peroxide Styrene Resin[8] E/VOLAN A, 181 glass cloth, with warp	0 (RT)	-0.0028 (20°K)
Paraplex P-43/Benzoyl Peroxide Styrene Resin[8] E/VOLAN A, 181 glass cloth, with weave	0 (RT)	-0.003 (20°K)

Table 4.69 Linear Thermal Expansion Coefficient of Composite Materials in Inches per Inch (cont.)

MATERIAL	α (upper temp)	α (lowest temp)
Paraplex P-43/Benzoyl Peroxide Styrene Resin[8] E/VOLAN A, 181 glass cloth, with thickness	0 (RT)	-0.0086 (20°K)
DC-2106/XY-15 Resin, E/140 HTS glass roving[8] normal to thickness	0 (RT)	-0.0014 (20°K)
DC-2106/XY-15 Resin, E/140 HTS glass roving[8] with thickness	0 (RT)	-0.0061 (20°K)
SC-1013 Resin, X-994/A-1100, 181 glass cloth[8] with warp	0 (RT)	-0.0012 (20°K)
SC-1013 Resin, X-994/A-1100, 181 glass cloth[8] with weave	0 (RT)	-0.0013 (20°K)
SC-1013 Resin, X-994/A-1100, 181 glass cloth[8] with thickness	0 (RT)	-0.0054 (20°K)
Molded Polyester Rod with Glass Fibers[12]	0.00291 (RT)	0 (0°K)

Table 4.69 Linear Thermal Expansion Coefficient of Composite Materials in Inches per Inch (cont.)

MATERIAL	α (upper temp)		α (lowest temp)	
Nylon, FM-1[8]	0	(RT)	-0.0139	(20°K)
Mylar[8]	0	(RT)	-0.007	(20°K)
FEP Teflon[8]	0	(RT)	-0.018	(20°K)
TFE Teflon[8]	0	(RT)	-0.0215	(20°K)
KEL-F[8]	0	(RT)	-0.011	(20°K)
Cast Phenolic Rod[12]	0.00889	(RT)	0	(0°K)
Nylon Rod[12]	0.01107	(RT)	0	(0°K)
Fluorothene[12]	0.01187	(RT)	0	(0°K)
Polystyrene[12]	0.01566	(RT)	0	(0°K)
Polyfluoroethylene[12]	0.02695	(RT)	0	(0°K)
Epon 828/DSA/1040/[27] BDMA (100/115.9/ 20/1)	0	(RT)	-0.015	(20°K)
Epon 828/DSA/BOHET/[27] BDMA (100/134/26/1)	0	(RT)	-0.016	(20°K)
Epon 826/Epon 871/[27] L-100/MDCA (35/15/ 50/27.6)	0	(RT)	-0.015	(20°K)
Epon 826/1040/Z-6077/[27] DSA/BDMA (80/20/20/ 115.9/1)	0	(RT)	-0.0162	(20°K)

Table 4.70 Linear Thermal Expansion Coefficient of Polymers in Inches per Inch

MATERIAL	ρ (upper temp)	ρ (lowest temp)
Pure Aluminum[10]	2.53×10^{-8} (RT)	1.695×10^{-10} (4.2°K)
1100-0[8]	1.27×10^{-8} (155.4°K)	2×10^{-9} (4.2°K)
2024-T4[8]	3.35×10^{-8} (49.8°K)	3.1×10^{-8} (4.2°K)
2024-T4[26]	4.35×10^{-8} (273°K)	1.742×10^{-8} (4.2°K)
2024-T6[26]	4×10^{-8} (273°K)	1.337×10^{-8} (4.2°K)
5052-0[8]	2.6×10^{-8} (99.8°K)	2×10^{-8} (4.2°K)
5083-0[26]	5.66×10^{-8} (273°K)	3.03×10^{-8} (4.2°K)
7039-0[26]	4.75×10^{-8} (273°K)	2.12×10^{-8} (4.2°K)

Table 4.71 Electrical Resistivity of Aluminum and Aluminum Alloys in Ohm-Meters

MATERIAL	ρ (upper temp)	ρ (lowest temp)
PURE COPPER		
Pure Copper[10]	1.55×10^{-8} (RT)	1.86×10^{-11} (4.2°K)
OFHC Copper[26]	1.559×10^{-8} (273°K)	1.6×10^{-10} (4.2°K)
COPPER-ZINC ALLOYS (BRASS)		
70/30 Brass[26]	6.65×10^{-8} (273°K)	4.22×10^{-8} (4.2°K)
Admiralty Brass[26]	6.93×10^{-8} (273°K)	4.56×10^{-8} (4.2°K)

Table 4.72 Electrical Resistivity of Copper and Copper Alloys in Ohm-Meters

MATERIAL	ρ (upper temp)	ρ (lowest temp)
Nickel[10]	6.14×10^{-8} (RT)	3.07×10^{-10} (4.2°K)
Hastelloy N[26]	1.206×10^{-6} (273°K)	1.201×10^{-6} (4.2°K)
Hastelloy X[26]	1.138×10^{-6} (273°K)	1.076×10^{-6} (4.2°K)
Inconel X[26], annealed	1.245×10^{-6} (273°K)	1.209×10^{-6} (4.2°K)
Inconel X[26], aged	1.229×10^{-6} (273°K)	1.176×10^{-6} (4.2°K)

Table 4.73 Electrical Resistivity of Nickel and Nickel Alloys in Ohm-Meters

MATERIAL	ρ (upper temp)	ρ (lowest temp)
PURE IRON		
Iron[10]	8.6×10^{-8} (RT)	5.59×10^{-10} (4.2°K)
STAINLESS STEEL-AUSTENITIC		
AISI 304L[26]	7.04×10^{-7} (273°K)	4.96×10^{-7} (4.2°K)
AISI 321[26]	7.39×10^{-7} (273°K)	5.36×10^{-7} (4.2°K)
17-7PH[26], annealed	1.015×10^{-6} (273°K)	9.68×10^{-7} (4.2°K)
17-7PH[26], precipitation hardened	7.09×10^{-7} (273°K)	5.75×10^{-7} (4.2°K)

Table 4.74 Electrical Resistivity of Ferrous Materials in Ohm-Meters

MATERIAL	ρ (upper temp)	ρ (lowest temp)
TITANIUM-ALPHA		
Titanium[10]	8×10^{-7} (RT)	8×10^{-8} (4.2°K)
TITANIUM-ALPHA-BETA		
Ti-6Al-4V[26]	1.675×10^{-6} (273°K)	1.469×10^{-6} (20°K)
TITANIUM-BETA		
Ti-13V-11Cr-3Al[26]	1.492×10^{-6} (273°K)	1.567×10^{-6} (4.2°K)
OTHER METALS		
Tantalum[10]	1.24×10^{-7} (RT)	2.48×10^{-9} (4.2°K)
Zirconium[10]	4.1×10^{-7} (RT)	1.64×10^{-8} (4.2°K)

Table 4.75 Electrical Resistivity of Titanium and Titanium Alloys and Other Metals in Ohm-Meters

MATERIAL	μ at 295°K	μ at 77°K	μ at 4.2°K
AISI 304[28]	1.25761×10^{-6}	1.25747×10^{-6}	NO DATA
AISI 304L[28]	1.25782×10^{-6}	1.25762×10^{-6}	NO DATA
AISI 310[28]	1.25668×10^{-6}	1.25678×10^{-6}	1.25802×10^{-6}
AISI 321[28]	1.25703×10^{-6}	1.25707×10^{-6}	1.25703×10^{-6}
Tenelon[28]	1.25666×10^{-6}	1.25666×10^{-6}	NO DATA

Table 4.76 Magnetic Permeability of Austenitic Stainless Steels in Webers Per Amp-Turn-Meter

BIBLIOGRAPHY FOR DATA TABLES

5. Campbell, J. E., Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures, Battelle Memorial Institute, DMIC Report No. 148, (February 14, 1961).

6. Lena, Adolph J., Letter to Professor Koichi Masubuchi, Ocean Engineering Department, M.I.T., from Vice-President, Research, Allegheny Ludlum Steel Corporation, Brackenridge, Pennsylvania, (April 2, 1970).

7. McClintock, R. M. and H. P. Gibbons, Mechanical Properties of Structural Materials at Low Temperatures, NBS Monograph 13, U. S. Government Printing Office, Washington, D. C., (1960).

8. Schwartzberg, F. R., et al., Cryogenic Materials Data Handbook, Volume I and Volume II, National Technical Information Service, Springfield, Virginia, (1970).

9. Johnson, Victor J., ed., A Compendium of the Properties of Materials at Low Temperatures, Phase I, Part II, Properties of Solids, National Technical Information Service, Springfield, Virginia, (October, 1960).

10. Johnson, Victor J., ed., A Compendium of the Properties of Materials at Low Temperatures, Phase II, National Technical Information Service, Springfield, Virginia, (December, 1961).

11. Low Temperature and Cryogenic Steels, Materials Manual, United States Steel Corporation, ADUSS-01-1206, Pittsburgh, Pennsylvania, (1964).

12. Scott, Russell B., Cryogenic Engineering, D. Van Nostrand Company, Inc., Princeton, N. J., (1967).

13. Childs, E., Lewis J. Ericks and Robert L. Powell, Thermal Conductivity of Solids at Room Temperature and Below, NBS Monograph 131, National Technical Information Service, Springfield, Virginia, (September, 1973).

16. Johnson, H. L., W. Powers, et al., "Accurate Measurement of Certain Physical Properties Down to 20°K", Advances in Cryogenic Engineering, Vol. 1, Plenum Press, New York, (1960), pp. 267-273.

17. Kropschot, R. H., R. M. McClintock and D. A. Van Gundy, "Mechanical Properties of Some Engineering Materials Between 20°K and 300°K", Advances in Cryogenic Engineering, Vol. 2, Plenum Press, New York, (1960), pp. 93-99.

18. Mikesell, R. P. and R. P. Reed, "The Impact Testing of Various Alloys at Low Temperatures", Advances in Cryogenic Engineering, Vol. 3, Plenum Press, New Tork, (1960), pp. 316-324.

19. Mikesell, R. P. and R. P. Reed, "The Tensile and Impact Strength of 5086 Aluminum Down to 20°K", Advances in Cryogenic Engineering, Vol. 4, Plenum Press, New York, (1960), pp. 101-113.

20. Reed, R. P., R. P. Mikesell and R. L. Gleeson, "Some Mechanical Properties of Magnesium Alloys at Low Temperatures", Advances in Cryogenic Engineering, Vol. 5, Plenum Press, New York, (1960), pp. 397-405.

21. Alleman, R. D. and G. C. Wolfer, "The Tensile and Impact Properties of Plate and Welds of Aluminum Alloys 5083-H113 Between 75 and -320°F", Advances in Cryogenic Engineering, Vol. 5, Plenum Press, New York, (1960), pp. 430-438.

22. Reed, R. P. and R. P. Mitchell, Low Temperature Mechanical Properties of Copper and Selected Copper Alloys, NBS Monograph 101, U. S. Government Printing Office, Washington, D. C., (1967).

23. Kaufman, J. G. and E. W. Johnson, "New Data on Aluminum Alloys for Cryogenic Applications", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, (1960), pp. 637-649.

24. Rice, L. P., J. E. Campbell and W. F. Simmons, "Tensile Behavior of Parent-Metal and Welded 5000 Series Aluminum Alloy Plate at Room and Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 7, Plenum Press, New York, (1962), pp. 478-489.

25. Coursen, J. W., J. G. Kaufman and W. E. Sicha, "Notch Toughness of Some Aluminum Alloy Castings at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 12, Plenum Press, New York, (1967), pp. 473-483.

25. Clark, A. F., G. E. Childs and G. H. Wallace, "Low Temperature Electrical Resistivity of Some Engineering Alloys", Advances in Cryogenic Engineering, Vol. 15, Plenum Press, New York, (1970), pp. 85-90.

27. Serafini, Tito T. and Jack L. Koenig, Cryogenic Properties of Polymers, Marcel Dekker, Inc., New York, (1968).

28. Campbell, J. E., "Thermal Conductivity, Resistivity, and Magnetic Susceptibility for Stainless Steels at Low Temperatures", MPC/MCIC Review of Metals Technology, Battelle Memorial Institute, Columbus, Ohio, (1 March 1974).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The principal conclusion which can be drawn from this thesis is that the entire area of cryogenic properties of materials is a relatively wide open field of research. Despite the large amount of experimental data in Tables 4.1 through 4.76, there are many knowledge gaps which will ultimately need to be filled. Cryogenic properties of materials in the areas of magnetic behavior, torsional behavior, electrical resistivity, specific heat and density are largely unexplored. On the other hand tensile properties, thermal conductivity and thermal expansion have been well researched. Notch toughness is in a class all by itself since, despite the large amount of data which exists, there is no general agreement on how to interpret this data.

With the decline in government funded research and development money, particularly by NASA and the United States Air Force, and the reluctance of large corporations to divulge their expensive private research efforts, the generation and dissemination of new data on the cryogenic properties of materials may have decreased significantly. There will probably always be a small but steady flow of new data from university research laboratories and government laboratories in many countries, but not on the same scale as in the past. This situation places the onus on a design agency to:

(1) Keep a continuous watch for newly published cryogenic property data which may be useful.

(2) Develope an in-house capability, however crude, to experimentally obtain data which cannot be found in the literature.

This thesis is a large first step in consolidating the data on cryogenic properties of materials which exists today into a single volume. Follow-on work could be done in one of three areas:

(1) Extending the data already provided by examining the references not already covered. This would be a tedious process, however, and it is questionable if the extensive effort required to do this would justify the results since many of the unused references are not in English or are very short articles covering just one property of one material.

(2) Explore the data available on the fabricability of materials for use at cryogenic temperatures. For example, some data was found on the behavior of weld metals at cyrogenic temperatures, but was not included in this work. There is probably a substantial amount of literature available on this and other subjects related to fabrication of materials for low temperature use, and this might very well prove to be a useful effort.

(3) Develope inexpensive and simple to build and use testing apparatus to provide cryogenic property data where none is available now. There are a great many references in the literature on testing procedures and testing apparatus and these would provide a good starting point.

One last recommendation is considered appropriate to anyone who becomes involved in searching the literature on cryogenic properties of materials. The authors of many articles and papers have a strong tendency to make definitive statements regarding how a group of materials or a specific material behaves at cryogenic temperatures. They make statements such as, "Material X has excellent notch toughness at liquid helium temperatures." Invariably there is no data in the article to support these claims and when data is finally found from some other source, it is not obvious why material X has such good notch toughness. Often such articles were written by the manufacturer of the materials, by someone whose research was supported by the manufacturer, or by someone who is attempting to draw conclusions from insufficient experimental data. It is felt that relying solely on the data, which may itself be questionable, and drawing one's own conclusions is a much better approach than believing statements such as that made above.

APPENDIX A

NATIONAL BUREAU OF STANDARDS LITERATURE SEARCH ON CRYOGENIC PROPERTIES OF MATERIALS

The purpose of this appendix is to provide a ready reference list to someone interested in finding information on cryogenic properties of materials.

The source of these references is a bibliography of references prepared on 24 October, 1973, for the staff of the Cryogenic Laboratory at M.I.T. by the Cryogenic Data Center, Institute for Basic Standards, National Bureau of Standards in Boulder, Colorado. The original bibliography of references is maintained in the M.I.T. Cryogenic Laboratory and contains many more entries than are presented here. In addition, the original provides general information on the content of each reference along with data concerning where the reference may be obtained.

What is provided here is a condensed version of the original with those references in foreign languages, some older outdated material, and any material not directly related to electrical machinery design eliminated. The material is broken into four major groups of materials: Composites; Nickel, Titanium, Aluminum Alloys and other Selected Alloys: Polymers; Steels. Within each material group there is a further breakdown into specific material properties which follow the breakdown in the original bibliography and basically match the properties given in Chapter 2.

The references are listed alphabetically within each material property group. If there is no reference listed under a group, this implies that the original had no reference. Following each reference is a multi-digit code. This number is the National Bureau of Standards file number for that reference. Knowing this number allows the researcher to use the original copy of the bibliography of references or permits smooth communication and information retrieval from the Cryogenic Data Center in Boulder, Colorado (telephone number 303-499-1000, extension 3257).

A.1 Cryogenic Properties of Composites

A.1.1 Mechanical Properties of Composites

A.1.1.1 Tensile Properties of Composites

Aerojet General Corporation, Cryogenic Tensile Properties of Selected Materials, Report No. 2712, NASA-CR-71751, Azusa, California, January, 1964, (38874).

Arden, B., Plastic and Elastomeric Foam Materials, Northrop Corp., Nortronics Division, Report No. NASA-CR-100463, Palos Verdes Estates, California, 1966, (63723).

Brink, N. O., "Mechanical Behavior of Reinforced Plastics at Cryogenic Temperatures", Technical Papers, 20th Annual Technical Conference of the Society of Plastics Engineers, Vol. 10, Sect. XV-2, 1964, pp. 1-19, (44537).

Christian, J. L. and M. D. Campbell, Mechanical and Physical Properties of Several Advanced Metal-Matrix Composite Materials, Cryogenic Engineering Conference, University of Colorado, Boulder, Colorado, Paper F2, August, 1972, (82408).

"Composites Show Promise as Cryogenic Materials", ASME Materials Research and Standards, Vol. 7, No. 9, September, 1967, (46048).

"Consider Composites for Cryogenic Conditions", Materials Engineering, Vol. 66, No. 6, November, 1967, pp. 68-70, (48261).

Dastin, S. J., "Bonded Beryllium Structures", Society of Aerospace Materials and Process Engineering, 9th National Symposium Papers, Western Periodicals Co., North Hollywood, California, November, 1965, pp. 1-15, (42036).

Davis, L. W., Properties of Aluminum-Steel Composites at Low Temperatures, ASTM 70th Annual Meeting, Paper No. 15, June, 1967, (47557).

Hanson, M. P., Glass-, Boron-, and Graphite-Filament-Wound-Resin Composites, Lewis Research Center Technical Memo X-52350, Cleveland, Ohio, 1968, (49222).

Hertz, J., An Evaluation of the Mechanical Properties of Adhesives at Cryogenic Temperatures and Their Correlation with Molecular Structure, General Dynamics/ Astronautics Report No., GDA-ERR-AN-196, San Diego, California, September, 1962, (54683).

Keys, R. D., T. F. Kiefer and F. R. Schwartzberg, "Cryogenic Properties of High-Strength Glass-Reinforced Plastics", Advances in Cryogenic Engineering, Vol. 11, Plenum Press, 1965, pp. 470-477, (33839).

Lewis, A. and G. E. Bush, Improved Cryogenic Resin/Glass-Filament-Wound Composites, Aerojet General Corp. Report No. 3392, Azusa, California, April, 1967, (48594).

Lewis, A., G. E. Bush and J. Creedon, Improved Cryogenic Resin/Glass-Filament-Wound Composites, Aerojet General Corp. Report No. NASA-CR-54867, Azusa, California, May, 1966, (39353).

Midgley, P., Structural Materials for Use at Cryogenic Temperatures, British Interplanetary Society 3rd Annual Symposium on Materials in Space Technology Paper, 1969, (63626).

Mowers, R., "Properties of Nonmetallic Materials at Cryogenic Temperatures", Proceedings of the 1968 Summer Study on Superconducting Devices and Accelerators, Part I, Brookhaven National Lab, Upton, N. Y., April, 1969, (61250).

Pepper, R. T., J. W. Upp, R. C. Rossi, and G. E. Kendall, Aluminum-Graphite Composites, Air Force Systems Command Report No. TR-0066 (9250-03)-3, Los Angeles, California, April, 1970, (77116).

Pride, R. A., B. A. Stein, and F. W. Schmidt, Mechanical Properties of Polymide-Resin/Glass-Fiber Laminates for Various Time, Temperature and Pressure Exposures, Society of the Plastics Industry Reinforced Plastics Technical Conference, 23rd, Paper, 1968, (51130).

Roseland, L. M., "Adhesives for Cryogenic Applications", Cryogenic Properties of Polymers, Ed. T. T. Serafini, Marcel Dekker, Inc., New York, 1968, pp. 17-28, (63601).

Rusch, K. C., "Energy-Absorbing Characteristics of Foamed Polymers", Journal of Applied Polymer Science, Vol. 14, No. 6, June, 1970, pp. 1433-1447, (68069).

Simon, R. A. and R. Alfring, Properties of Graphite Fiber Composites at Cryogenic Temperatures, College Park, Maryland, Scientific and Technical Information Facility Report No. NASA-CR-72652, May, 1970, (74370).

Soffer, L. M. and R. Molho, Cryogenic Resins for Glass-Filamant-Wound Composites, Aerojet General Corp. Report No. 3343, Azusa, California, January, 1967, (48278).

Soffer, L. M. and R. Molho, Mechanical Properties of Epoxy Resins and Glass/Epoxy Composites at Cryogenic Temperatures, Aerojet General Corp. Report No. NASA-CR-84451, Azusa, California, 1967, (47601).

Toth, L. W., "Properties of Glass-Reinforced Epoxy Through the 20 Degree K Range", Modern Plastics, Vol. 42, No. 12, August, 1965, pp. 123-130, (31476).

Wigley, D. A., Mechanical Properties of Materials at Low Temperatures, Plenum Press, Inc., New York, 1971, (75205).

A.1.1.2 Proportional Limit of Composites

NONE

A.1.1.3 Elastic Modulii of Composites

Arden, B., Plastic and Elastomeric Foam Materials, Northrop Corp., Nortronics Division Report No. NASA-CR-100463, Palos Verdes Estates, California, 1966, (63723).

Hertz, J., An Evaluation of the Mechanical Properties of Adhesives at Cryogenic Temperatures and Their Correlation with Molecular Structure, General Dynamics/Astronautics Report No. GPA-ERR-AN-196, San Diego, California, September, 1962, (54683).

Keys, R. D., T. F. Kiefer and F. R. Schwartzberg, "Cryogenic Properties of High-Strength Glass-Reinforced Plastics", Advances in Cryogenic Engineering, Vol. 11, Plenum Press, 1965, pp. 470-477, (33839).

Rusch, K. C., "Energy-Absorbing Characteristics of Foamed Polymers", Journal of Applied Polymer Science, Vol. 14, No. 6, June, 1970, pp. 1433-1447, (68069).

A.1.1.4 Poisson's Ratio of Composites

NONE

A.1.1.5 Elongation and Reduction in Area of Composites

NONE

A.1.1.6 Torsional Properties of Composites

Lavengood, R. E. and R. M. Anderson, "Matrix Properties Controlling Torsional Fatigue Life of Fiber Reinforced Composites", Proceedings of the 24th Annual Technical Conference, February, 1969, Society of the Plastics Industry, (60989).

A.1.1.7 Notch Toughness of Composites

"Composites Show Promise as Cryogenic Materials", ASME Materials Research and Standards, Vol. 7, No. 9, September, 1967, (46048).

Soffer, L. M. and R. Molho, Cryogenic Resins for Glass-Filament-Wound Composites, Aerojet General Corp. Report No. 3343, Azusa, California, January, 1967, (48278).

Soffer, L. M. and R. Molho, Mechanical Properties of Epoxy Resins and Glass/Epoxy Composites at Cryogenic Temperatures, Aerojet General Corp. Report No. NASA-CR-84451, Azusa, California, 1967, (47601).

A.1.1.8 Fatigue Properties of Composites

Brink, N. O., "Mechanical Behavior of Reinforced Plastics at Cryogenic Temperatures", 20th Annual Technical Conference, Society of Plastics Engineers, Vol. 10, Section XV-2, 1964, pp. 1-19, (44537).

Dastin, S. J., "Bonded Beryllium Structures", Society of Aerospace Materials and Process Engineering, 9th National Symposium Papers, Western Periodicals Co., North Hollywood, California, November, 1965, pp. 1-15, (42036).

Roseland, L. M., "Adhesives for Cryogenic Applications", Cryogenic Properties of Polymers, Ed. T. T. Serafini, Marcel Dekker, Inc., New York, 1968, pp. 17-28, (63601)

A.1.2 Thermophysical Properties of Composites

A.1.2.1 Thermal Conductivity of Composites

Campbell, M. D., J. F. Hoskins, G. L. O'Barr and J. Hertz, "Thermophysical Properties of Reinforced Plastics at Cryogenic Temperatures", Journal of Spacecraft and Rockets, Vol. 3, No. 4, April, 1966, pp. 596-599, (35323).

Campbell, M. D., A. L. O'Barr and J. Hertz, Thermophysical Properties of Plastic Materials and Composites to Liquid Hydrogen Temperature, General Dynamics/Astronautics Report No. BVJ-63-001-8, San Diego, California, November, 1964, (28393).

Evaluation of the Thermal Properties of Materials, Avco Corp. Report No. NASA-CR-65979, Lowell, Massachusetts, September, 1966, (52682).

Fried, E. and G. Hieser, Measurement of Thermal Conductance of Multilayer and Other Insulation Materials, General Electric Co., Missile and Space Division Report No. NASA-CR-92329, Philadelphia, Penn., August, 1968, (56847).

Garrett, K. W. and H. M. Rosenberg, "The Thermal Conductivity of Epoxy Resin/Powder Composites at Low Temperatures", 4th International Cryogenic Engineering Conference, Proceedings, IPC Science and Technology Press, Ltd., Guilford, England, 1972, pp. 267-269, (85395).

Hertz, J. and J. F. Haskins, "Thermal Conductivity of Reinforced Plastics at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 10, Plenum Press, New York, 1965, pp. 163-170, (34339).

Hertz, J., J. F. Haskins, J. L. Percy and M. D. Campbell, The Determination of Thermophysical Properties of Plastic Materials and Composites at Cryogenic Temperatures, General Dynamics/Astronautics Quarterly Progress Report No. 4, San Diego, California, July, 1963, (19540).

Hertz, J. and D. Knowles, Survey of Thermal Properties of Selected Materials, General Dynamics/Convair Report No. ZZL-65-008, San Diego, California, February, 1965, (34723).

Kingsbury, J. E., New and Proposed Cryogenic Temperature Resistant Plastics, SAE Aeronautic and Space Engineering and Manufacturing Meeting, Paper No. 660638, Los Angeles, California, October, 1966, (44395)

Moeller, C. E., J. B. Loser, W. E. Snyder and V. Hopkins, Thermophysical Properties of Thermal Insulating Materials, Midwest Research Institute Technical Documentary Report No. ASK-TDR-215, Kansas City, Missouri, July, 1962, (13888).

Toth, L. W., "Properties of Glass-Reinforced Epoxy Through the 20 Degree K Range", Modern Plastics, Vol. 42, No. 12, August, 1965, pp. 1230 130, (31476).

Toth, L. W., T. J. Boller, and I. R. Butcher, Program for the Evaluation of Structural Reinforced Plastic Materials at Cryogenic Temperatures, Goodyear Aerospace Corp., Report No. GER-12792, Akron, Ohio, August, 1966, (42242).

Wigley, D. A., "Mechanical Properties of Materials at Low Temperatures", Cryogenics, Vol. 8, No. 1, February, 1968, pp. 2-12, (49672).

A.1.2.2 Specific Heat of Composites

Arden, B., Plastic and Elastomeric Foam Materials, Northrop Corp., Nortronics Division Report No. NASA-CR-100463, Palos Verdes Estates, California, 1966, (63723).

Campbell, M. D., J. F. Haskins, G. L. O'Barr and J. Hertz, "Thermophysical Properties of Reinforced Plastics at Cryogenic Temperatures", Journal of Spacecraft and Rockets, Vol. 3, No. 4, April, 1966, pp. 596-599, (35323).

Campbell, M. D., J. Hertz and G. L. O'Barr, Thermophysical Properties of Plastic Materials and Composites to Liquid Hydrogen Temperature, General Dynamics/Astronautics Report No. ML-TDR-64-33, San Diego, California, March, 1965, (31065).

Christian, J. L. and M. D. Campbell, Mechanical and Physical Properties of Several Advanced Metal-Matrix Composite Materials, Cryogenic Engineering Conference, University of Colorado, Boulder, Colorado, Paper F2, August, 1972, (82408).

Hertz, J. and D. Knowles, Survey of Thermal Properties of Selected Materials, General Dynamics/Convair Report No. ZZL-65-008, San Diego, California, February, 1965, (34723).

A.1.2.3 Thermal Expansion of Composites

Campbell, M. D., G. L. O'Barr and J. Hertz, Thermophysical Properties of Plastic Materials and Composites to Liquid Hydrogen Temperature, General Dynamics/Astronautics Report No. BVJ-63-001-8, San Diego, California, November, 1964, (28393).

Christian, J. L. and M. D. Campbell, Mechanical and Physical Properties of Several Advanced Metal-Matrix Composite Materials, Cryogenic Engineering Conference, University of Colorado, Boulder, Colorado, Paper F2, August, 1972, (82408).

Hamilton, W. O., D. B. Greene and D. E. Davidson, "Thermal Expansion of Epoxies Between 2 and 300 Degrees K", Review of Scientific Instrumentation, Vol. 39, No. 5, May, 1968, pp. 645-648, (50789).

Hertz, J., J. F. Haskins, J. L. Percy and M. D. Campbell, The Determination of Thermophysical Properties of Plastic Materials and Composites at Cryogenic Temperatures, General Dynamics/Astronautics Quarterly Progress Report No. 4, San Diego, California, July, 1963, (19540).

Lewis, A. and G. E. Bush, Improved Cryogenic Resin/Glass-Filament-Wound Composites, Aerojet General Corp. Report No. NASA-CR-72163, Azusa, California, April, 1967, (48594).

Soffer, L. M. and R. Molho, Cryogenic Resins for Glass-Filament-Wound Composites, Aerojet General Corp. Report No. 3343, Azusa, Californai, January, 1967, (48278).

Soffer, L. M. and R. Molho, Mechanical Properties of Epoxy Resins and Glass/Epoxy Composites at Cryogenic Temperatures, Aerojet General Corp. Report No. NASA-CR-84451, Azusa, California, 1967, (47601).

Toth, L. W., "Properties of Glass-Reinforced Epoxy Through the 20 Degree K Range", Modern Plastics, Vol. 42, No. 12, August, 1965, pp. 123-130, (31476).

A.1.2.4 Density of Composites

Arthur D. Little, Inc., Advanced Studies on Multilayer Insulation Systems, Report No. ADL-67180-00-04, June, 1966, (46753).

Campbell, M. D., G. L. O'Barr, J. F. Haskins and J. Hertz, Thermophysical Properties of Plastic Materials and Composites to Liquid Hydrogen Temperature, General Dynamics/Convair Report No. ML TDR-64-33-PT-3, San Diego, California, August, 1965, (34072).

Hertz, J., J. F. Haskins, J. L. Percy and M. D. Campbell, "The Determination of Thermophysical Properties of Plastic Materials and Composites at Cryogenic Temperatures", General Dynamics/ Astronautics Quarterly Progress Report No. 4, San Diego, California, July, 1963, (19540).

Toth, L. W. and R. A. Buckley, "Mechanical Response at Cryogenic Temperatures of Selected Reinforced Plastic Composite Systems", ASTM Paper No. 16, ASTM 70th Annual Meeting, June 25-30, 1967, (48368).

A.1.3 Electrical Conductivity of Composites

Kingsbury, J. E., Nonstructural Materials for Aerospace Application, ASME Winter Annual Meeting, Paper No. ASME 67-WA/AV-6, Pittsburgh, Pennsylvania, November 1967, (49621).

A.1.4 Magnetic Properties of Composites

McInturff, A. D., "Composite Materials", Proceedings of the 1968 Summer Study on Superconducting Devices and Accelerators, Brookhaven National Lab Report No. BNL-50155, Upton, New York, April, 1969, (63303).

Meunier, F., J. P. Burger, G. Deutscher and P. A. Van Dalen, "Proximity Effects Between Superconductors and Ferromagnetic Domains", Physics Letters, Vol. 24A, No. 13, June, 1967, pp. 722-724, (46483).

A.2 Cryogenic Properties of Nickel, Titanium and Aluminum Alloys and Other Selected Alloys

A.2.1 Cryogenic Properties of Nickel Alloys

A.2.1.1 Mechanical Properties of Nickel Alloys

A.2.1.1.1 Tensile Properties of Nickel Alloys

Campbell, J. E., Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures, Battelle Memorial Institute Report No. 148, February, 1961, (10328).

Christian, J. L., "Mechanical Properties of Several Nickel Base Alloys at Room and Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 12, Plenum Press, Inc., New York, 1967, pp. 520-531, (42314).

Christian, J. L., C. T. Yang and W. E. Witzell, Physical and Mechanical Properties of Pressure Vessel Material for Application in a Cryogenic Environment, General Dynamics/Astronautics, San Diego, Report No. GD/A 63-0818-3, 1964, (25238).

"Effect of Low Temperatures on Structural Metals", Light Metal Age, Vol. 23, No. 1/2, February, 1965, pp. 14-19, (30706).

Eldridge, E. A. and H. W. Deem, Report on Physical Properties of Metals and Alloys from Cryogenic to Elevated Temperatures, American Society of Testing Materials, Special Technical Publication No. 296, April, 1961, (10667).

Hurlich, A., "Low Temperature Metals", Proceedings of the 1968 Summer Study on Superconducting Devices and Accelerators, Part I, Brookhaven National Lab, Upton, N. Y., April, 1969, (71249).

Kendall, E. G., Metals and Alloys for Cryogenic Applications - A Review, Aerospace Corporation, Report No. TDR-269, El Segundo, California, January, 1960, (22460).

Kieffer, T. F., R. D. Keys and F. R. Schwartzberg, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colorado, Report No. CR-65-70, October, 1965, (31808).

Martin, H. L. and A. G. Ingram, "Effects of Low Temperatures on Structural Metals", Journal of Metals, Vol. 17, No. 7, July, 1965, (31049)

McClintock, R. M. and H. P. Gibbons, A Compilation of Mechanical Properties of Materials at Cryogenic Temperatures, NBS Report No. 6064, July, 1959, (4413).

Midgely, P., "Structural Materials for Use at Cryogenic Temperatures", Journal of British Interplanetary Society, Vol. 23, No. 9, September, 1970, pp. 597-606, (75941).

Mikesell, R. P. and R. P. Reed, "The Impact Testing of Various Alloys at Low Temperatures", Advances in Cryogenic Engineering, Vol. 3, Plenum Press, Inc., New York, 1960, pp. 316-324, (8908).

Nachtigall, A. J., S. J. Klima and J. C. Freche, Fatigue of Liquid Rocket Engine Metals at Cryogenic Temperatures to -452 Degrees F, NASA, Lewis Research Center, Cleveland, Ohio, Technical Note, No. D-4274, December, 1967, (48997).

Rosenberg, S. J., Nickel and Its Alloys, NBS Monograph 106, May, 1968, (54076).

Rowdon, S., "Engineering Steels and Alloys for Low Temperature Service", Engineering Materials Design, Vol. 5, March, 1962, pp. 191-196, (25114).

Some Properties of Inco Nickel Alloys at Low Temperatures, International Nickel Company, New York, (11206).

Uzhik, G. W., "The Low Temperature Strength and Ductility of Metals", Engineering Institute of the Academy of Sciences, U.S.S.R., Moscow, 1957, (13946).

Viglione, J. and W. F. Worden, Fracture Toughness Properties of Some Alloy Steels and Aluminum and Titanium Alloys, Naval Air Engineering Center, Aeronautical Materials Lab Report No. NAEC-AML-2111, Philadelphia, March, 1965, (29137).

Warren, R. A. and R. P. Reed, Tensile and Impact Properties of Selected Materials from 20 to 300 Degrees K, NBS Monograph No. 63, June, 1963, (17164).

Watson, J. F., "Materials at Cryogenic Temperatures", Materials for Missiles and Spacecraft, McGraw Hill Book Company, Inc., 1963, pp. 25-43, (21060).

Watson, J. F. and J. L. Christian, "Low Temperature Properties of K-Monel, Inconel-X, Rene 41, Haynes 25 and Hastelloy B Sheet Alloys", Journal of Basic Engineering, Vol. 84D, No. 2, June, 1962, pp. 265-277, (12395).

Witzell, W. E., Fracture Data for Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. GDC-ZZL-67-017, November, 1967, (52334).

Yang, C. T., Cryogenic Temperature Dependence of the Yield Strength of High-Strength Alloys, ASME Metals/Production Engineering Conference Paper No. 65-PROD-14, Berkeley, California, June, 1965, (29898).

A.2.1.1.2 Proportional Limit of Nickel Alloys

NONE

A.2.1.1.3 Elastic Modulii of Nickel Alloys

Christian, J. L., C. T. Wang and W. E. Witzell, Physical and Mechanical Properties of Pressure Vessel Material for Application in a Cryogenic Environment, General Dynamics/Astronautics, San Diego, Report No. GD/A 63-0818-3, 1964, (25238).

Kieffer, T. F., R. D. Keys and F. R. Schwartzberg, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colorado, Report CR-67-70, October, 1965, (31808).

Nachtigall, A. J., S. J. Klima and J. C. Freche, Fatigue of Liquid Rocket Engine Metals at Cryogenic Temperatures to -452 Degrees F, NASA, Lewis Research Center, Cleveland, Ohio, Technical Note, No. D-4274, December, 1967, (48997).

Spinner, S. and A. G. Rozner, "Elastic Properties of NITI as a Function of Temperature", Journal of the American Acoustic Society, Vol. 40, No. 5, November, 1966, (44018).

Witzell, W. E., Fracture Data for Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. GDC-ZZL-67-017, November, 1967, (52334).

A.2.1.1.4 Poisson's Ratio of Nickel Alloys

NONE

A.2.1.1.5 Elongation and Reduction in Area of Nickel Alloys

Hurlich, A., "Materials Requirements for Cryogenic Temperature Applications", Materials Science and Technology for Advanced Application, Prentice Hall, Inc., Englewood Cliffs, N. J., 1962, pp. 45-84, (16139).

A.2.1.1.6 Torsional Properties of Nickel Alloys

Bower, D. I., E. Claridge and I. S. T. Tsong, "Low Temperature Elastic Constants and Specific Heats of F. C. C. Nickel-Iron Alloys", Physical Status of Solids, Vol. 29, No. 2, October, 1968, pp. 616-625, (58396).

Leamy, H. J. and H. Warlimont, "The Elastic Behavior of Ni-Co Alloys", Physical Status of Solids, Vol. 37, No. 2, February, 1970, pp. 523-534, (69404).

A.2.1.1.7 Notch Toughness of Nickel Alloys

Sachs, Bruno, "Toughness and Ductility of Metals", Machine Design, Vol. 36, No. 28, December, 1964, pp. 157-260, (26035).

Viglione, J. and W. F. Worden, Fracture Toughness Properties of Some Alloy Steels and Aluminum and Titanium Alloys, Naval Air Engineering Center, Aeronautical Materials Laboratory, Philadelphia, Report No. NAEC-AML-2111, March, 1965, (29137).

Wells, C. and W. B. Triplett, Energy of Crack Formation and Crack Propagation under Impact Loading, Carnegie Institute of Technology, Metals Research Lab, Pittsburg, Pa., Technical Note 60-124, August, 1960, (10138).

Witzell, W. E., Fracture Data for Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, California, Report No. GDC-ZZL-67-017, November, 1967, (52334).

A.2.1.1.8 Fatigue Properties of Nickel Alloys

Gideon, D. N., R. J. Favor, H. J. Grover and G. M. McClure, "The Fatigue Behavior of Certain Alloys in the Temperature Range from Room Temperature to -424 Degrees F", Advances in Cryogenic Engineering, Vol. 7, Plenum Press, Inc., New York, 1962, pp. 503-508, (15385).

Kieffer, T. F., R. D. Keys, F. R. Schwartzberg, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colorado, Report No. CR-65-70, October, 1965, (31808).

Malin, C. O. and E. H. Schmidt, Tensile and Fatigue Properties of Alloy 718 at Cryogenic Temperatures, National Metals Congress, Cleveland, Ohio, Paper No. 28, October, 1967, (48993).

Nachtigall, A. J., S. J. Klima and J. C. Freche, Fatigue of Liquid Rocket Engine Metals at Cryogenic Temperatures to -452 Degrees F, NASA, Lewis Research Center Technical Note No. D-4274, December, 1967, (48997).

Wolff, R. P. and R. A. Dodd, "Fatigue Properties of Some Age-Hardened Alloys", Materials Research Standards, Vol. 3, No. 9, September, 1963, pp. 734-735, (20175).

A.2.1.2 Thermophysical Properties of Nickel Alloys

A.2.1.2.1 Thermal Conductivity of Nickel Alloys

Berger, L., Conduction Processes in Ferromagnetic Alloys, Army Research Office, Durham, N. C., Report No. 1 - Final, March, 1969, (68731).

Farrell, T. and D. Grieg, "The Thermal Conductivity of Nickel and Its Alloys", Proceedings of the Physical Society, London, Ser. 2, Vol. 2, No. 8, August, 1969, pp. 1465-1473, (71600).

Grieg, D. and J. P. Harrison, "The Low Temperature Electrical Transport Properties of Nickel and Dilute Nickel-Copper Alloys", Philosophy Magazine, Vol. 12, No. 115, July, 1965, pp. 71-79, (30172).

Hust, J. G. and L. L. Sparks, Thermal Conductivity, Electrical Resistivity and Thermo-power of Aerospace Alloys from 4 to 300 K, NBS Report No. 9775, November, 1970, (70556).

Powers, R. W., J. B. Ziegler and H. L. Johnston, The Thermal Conductivity of Metals and Alloys at Low Temperatures Between 25 and 300 Degrees K, Ohio State University, Columbus, Ohio, Technical Report No. 264-8, April, 1951, (344).

Some Properties of Inco Nickel Alloys at Low Temperatures, International Nickel Company, Development Research Division, New York, (11206).

Watson, T. W. and D. R. Flynn, "Thermal Conductivity of Four Heat Resistant Alloys", Transactions, Metals Society, Vol. 242, May 1968, pp. 844-846, (56256).

A.2.1.2.2 Specific Heat of Nickel Alloys

Bower, D. I., E. Claridge and I. J. T. Tsong, "Low Temperature Elastic Constants and Specific Heats of FCC Nickel Iron Alloys", Physical Status of Solids, Vol. 29, No. 2, October, 1968, pp. 617-625, (58396).

Clougherty, E. V. and L. Kaufman, The Thermodynamic Properties of Alpha F.C.C. Nickel-Zinc Alloys, ManLabs, Inc., Cambridge, Mass., Technical Report No. 6, February, 1963, (28136).

Dixon, M., F. E. Hoare and T. M. Holden, "The Low Temperature Specific Heats of Some Nickel Based Iron and Copper Alloys", Proceedings of the Royal Society, Ser. A, Vol. 303, No. 1474, 1968, pp. 339-354, (55284).

Ehrlich, A. C., R. Ehrat and D. Rivier, "Low Temperature Specific Heat Measurements in Some Ni Based Alloys", Helva Physica Acta, Vol. 39, November, 1966, pp. 598, (44013).

Grew, K. E., "The Specific Heat of Nickel and Some Nickel-Copper Alloys", Proceedings of the Royal Society, Vol A145, London, 1934, pp. 50[illegible]22, (22806).

Gupta, K. P., C. H. Cheng and P. A. Beck, "Low Temperature Specific Heat of F.C.C. Alloys of 3D - Transition Elements", Physical Chemistry of Solids, Vol. 25, No. 1, January, 1964, pp. 73-83, (22798).

Ho, J. C. and R. Viswanathan, "Low Temperature Specific Heat of F.C.C. Ni-Co Alloys", Physical Review, Vol. 172, No. 3, August, 1968, pp. 705-709, (52849).

Moody, D. E., M. G. Staveley and R. Kuentzler, "Low Temperature Specific Heats of Nickel-Chronium Alloys", Physical Letters, Vol. 33A, No. 4, November, 1970, pp. 244-245, (75811).

Volkenshteyn, V. V. and Iu. V. Tsiovkin, "Thermal Capacity of Alloys of the Ni-Mn System in the Temperature Range 13-300 Degrees K", Physical Metals Metallog, Vol. 15, March, 1964, pp. 46-67, (25297).

A.2.1.2.3 Thermal Expansion of Nickel Alloys

Arp, V., J. H. Wilson, L. Winrich and P. Sikora, "Thermal Expansion of Some Engineering Materials from 20 to 293 Degrees K", Cryogenics, Vol. 2, June, 1962, pp. 230-235, (12732).

Clark, A. F., "Low Temperature Thermal Expansion of Some Metallic Alloys", Cryogenics, Vol. 8, No. 5, October, 1968, pp. 282-289, (54322).

Some Properties of Inco Nickel Alloys at Low Temperatures, International Nickel Company, Development Research Division, New York, (11206).

A.2.1.2.4 Density of Nickel Alloy

Some Properties of Nickel Alloys at Low Temperatures, International Nickel Company, Inc., New York, (11206).

A.2.1.3 Electrical Conductivity of Nickel Alloys

Armstrong, E. E. and R. Fletcher, "Resistivity and Thermopower of a Series of Ni-Fe Invar Alloys", Canadian Journal of Physics, Vol. 50, No. 3, February, 1972, pp. 244-250, (77304).

Berger, L., Conduction Processes in Ferromagnetic Alloys, Army Research Office, Durham, N. C., Report No. AROD-6125-9-P, March 1970, (71293).

Clark, A. F., G. E. Childs and G. H. Wallace, "Electrical Resistivity of Some Engineering Alloys at Low Temperature", Cryogenics, Vol. 10, No. 4, August, 1970, pp. 295-305, (66997).

Clark, A. F., G. E. Childs and G. H. Wallace, "Low Temperature Electrical Resistivity of Some Engineering Alloys", Advances in Cryogenic Engineering, Vol. 15, Plenum Press, Inc., New York, 1970, pp. 85-90, (58031).

Erdmann, J. C. and J. A. Jahoda, Thermal Conductivity of Copper-Nickel Alloys at 4.2°K, Boeing Science Research Lab, Seattle, Washington, Report No. D1-82-0333, April, 1964, (23544).

Farrell, T. and D. Grieg, "The Electrical Resistivity of Nickel and Its Alloys", Proceedings of the Physical Society, London, Ser. 2, Vol. 1, No. 5, October, 1968, pp. 1359-1369, (58134).

Grieg, D. and J. P. Harrison, "The Low Temperature Electrical Transport Properties of Nickel and Dilute Nickel-Copper Alloys", Philosophy Magazine, Vol. 12, No. 115, July, 1965, pp. 71-79, (30172).

Hust, J. A. and L. L. Sparks, Thermal Conductivity, Electrical Resistivity and Thermo-Power of Aerospace Alloys from 4 to 300 K, NBS Report No. 9775, November, 1970, (70556).

Kondorsky, E., O. J. Glakina and L. A. Tchermickova, "Nature of Electrical Resistivity of the Ferromagnetic Metals at Low Temperatures", Journal of Applied Physics, Vol. 29, No. 3, 1958, pp. 243-246, (3603).

Masharov, S. I., "Electrical Resistivity of Binary Ferromagnetic Alloys", Physical Metals Metallog, Vol. 21, No. 4, pp. 4-5, (44417).

Park, O. E., M. M. Fulk and M. M. Reynolds, "Low Temperature Electrical Resistance of Fifteen Commercial Conductors", Advances in Cryogenic Engineering, Vol. 1, Plenum Press, Inc., New York, 1960, pp. 156-157, (8828).

Some Properties of Inco Nickel Alloys at Low Temperatures, International Nickel Company, Development Research Division, New York, (11206).

A.2.1.4 Magnetic Properties of Nickel Alloys

Ackermann, F. W., W. A. Klawitter and J. J. Drautman, Magnetic Properties of Commercial Soft Magnetic Alloys at Cryogenic Temperatures, 16th Cryogenic Engineering Conference, Boulder, Colorado, Paper No. C-4, (66007).

Berger, L., Conduction Processes in Ferromagnetic Alloys, Army Research Office, Durham, N. C., Report No. 1-Final, March, 1969, (68731).

Efferson, K. R. and W. J. Leonard, Magnetic Properties of Some Structural Materials Used in Cryogenic Applications, Oak Ridge, Lab, Tenn., Report No. ORNL-4150, September, 1967, (51283).

Kondorsky, E. I., V. E. Rode and V. Gofmann, "The Saturation Magnetization of Nickel-Copper Alloys at Low Temperatures", Soviet Physics, Vol. 8, 1959, pp. 380-381, (2024).

Rode, V. E. and R. Herrmann, "The Investigation of the Temperature Dependence of Saturation Magnetization of Some Ferromagnetic Metals at Low Temperatures", Proceedings of the International Conference on Magnetism, London, 1965, pp. 146-148, (33994).

Smit, J., "Magnetoresistance of Ferromagnetic Metals and Alloys at Low Temperatures", Physica, Vol. 17, 1951, pp. 612-627, (5291).

Some Properties of Inco Nickel Alloys at Low Temperatures, International Nickel Company, Development Research Division, New York, (11206).

Van Elst, H. C., B. Luback and G. J. Van Den Berg, "The Magnetization of Some Nickel Alloys in Magnetic Fields Up to 15 KOE Between 0 Degrees K and 300 Degrees K", Physica, Vol. 28, December, 1962, pp. 1297-1317, (14676).

Wallace, W. R. and R. J. Craig, Thermal Structural and Magnetic Studies of Metals and Intermetallic Compounds , Pittsburg University, Pennsylvania, Report No. NYO-3451-1, 1965, (36361).

A.2.2 Cryogenic Properties of Titanium Alloys

A.2.2.1 Mechanical Properties of Titanium Alloys

A.2.2.1.1 Tensile Properties of Titanium Alloys

Campbell, J. E., Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures, DMIC, Battelle Memorial Institute, Columbus, Ohio, Report No. 148, February, 1961, (10528).

Campbell, J. E., Review of Recent Developments in the Evaluation of Special Metal Properties, Battelle Memorial Institute, Columbus, Ohio, DMIC Report No. 94, March, 1961, (10697).

Christian, J. L., Mechanical Properties of High Strength Sheet Materials at Cryogenic Temperatures, General Dynamics/ Astronautics, San Diego, Report No. ERR-AN-255, November, 1962, (16854).

Christian, J. L., Mechanical Properties of Titanium and Titanium Alloys at Cryogenic Temperatures, General Dynamics Corp., Convair Astronautics Division Report No. MGR-189, October, 1960, (11856).

Christian, J. L., J. E. Chafey, A. Hurlich, J. F. Watson and W. E. Witzell, "A Study of Brittle Fracture in Cryogenic Alloys", Metal Progress, Vol. 83, No. 5, May, 1963, pp. 103-106, (18519).

Christian, J. L. and A. Hurlich, "Mechanical Properties of Titanium Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 13, Plenum Press, New York, 1968, (47515).

Cryogenic Tensile Properties of Selected Materials, Aerojet General Corporation, Azusa, Claifornia, Report No. 2712, January, 1964, (38874).

"Effect of Low Temperatures on Structural Metals", Light Metal Age, Vol. 23, No. 1, February, 1965, pp. 14-19, (30706).

Holden, F. C., F. R. Schwartzberg and H. R. Ogden, Report on Tensile Properties of Titanium Alloys at Low Temperatures, DMIC, Battelle Memorial Institute, Columbus, Ohio, Report 107, January, 1959, (4682).

Hurlich, A., The Cryogenic Behavior of Titanium, Titanium Metallurgy Course, New York University, New York, Lecture 7, September, 1965, (33379).

Martin, H. L., Effects of Low Temperatures on Structural Metals, NASA Special Publication No. SP-5012, December, 1964, (24746).

Martin, H. L. and A. G. Ingram, "Effects of Low Temperature on Structural Metals", Journal of Metals, Vol. 17, No. 7, July, 1965, p. 735, (31049).

McGee, R. L., J. E. Campbell, R. L. Carlson, et al., The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures, Battelle Memorial Institute, Columbus, Ohio, WADC Technical Report No. 58-386, November, 1958, (7507).

Mote, M. W., R. B. Hooper and P. D. Frost, The Engineering Properties of Commerical Titanium Alloys, Battelle Memorial Institute, Columbus, Ohio, TML Report No. 92, June, 1958, (4448).

Nachtigall, A. J., S. J. Klima and J. C. Freche, Fatigue Behavior of Rocket Engine Materials to 4 Degrees K, 14th Cryogenic Engineering Conference, Cleveland, Ohio, Paper C-4, August 1968, (52709).

Schwartzberg, F. R., R. D. Keys, M. J. Brown and C. L. Reightler, Determination of Low Temperature Fatigue Properties of Aluminum and Titanium Alloys, Martin Co., Denver, Colorado, Annual Summary Report, NASA CR-55027, July, 1963, (22873).

Schwartzberg, F. R., T. F. Kiefer and R. D. Keys, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, 1 April 1962 Through 30 September 1964, Martin Co., Denver, Colorado, Report No. CR-64-74, October, 1964, (23894).

"Two Titanium Alloys for -432 Degrees F", Materials in Design Engineering, Vol. 56, No. 1, July, 1962, (26559).

Warren, K. A. and R. P. Reed, Tensile and Impact Properties of Selected Materials From 20 to 300 Degrees K, NBS Monograph No. 63, June, 1963, (17164).

Watson, J. F., Properties of Engineering Materials at Extreme Subzero Temperatures with Supplementary Information on Liquid Hydrogen, General Dynamics/Astronautics, San Diego, Report No. EMG-44, December, 1958, (26346).

Watson, J. F., J. L. Christian and J. Hertz, Selection of Materials for Cryogenic Applications in Missiles and Aerospace Vehicles, General Dynamics/Astronautics, San Diego, Report No. MGR-132-1, February, 1960, (14833).

Weiman, S. M., Cryogenic Properties of Seven Experimental Titanium Alloys, Douglas Aircraft Co., Inc., Missile and Space Systems Division, Santa Monica, California, Report No. SM-44674, March, 1964, (23522).

Witzell, W. E., Fracture Data for Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. GDC-ZZL-67-017, November, 1967, (52334).

Yang, C. T., "Cryogenic Temperature Dependence of the Yield Strength of High Strength Alloys", Journal of Engineering Industry, Vol. 88, No. 1, February, 1966, pp. 117-128, (33904).

A.2.2.1.2 Proportional Limit of Titanium Alloys

Morris, E. E., Glass-Fiber-Reinforced Metallic Tank for Cryogenic Service, Aero-jet General Corporation, Azusa, Calif., Report No. NASA-CR-72224, June, 1967, (50623).

A.2.2.1.3 Elastic Modulii of Titanium Alloys

Christian, J. L. and A. Hurlich, "Mechanical Properties of Titanium Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 13, Plenum Press, New York, 1968, (47515).

Kovtun, S. F. and R. A. Ulyanov, "Influence of Alloying on the Temperature Dependence of the Normal Elasticity Modulus of Titanium", Physical Metals Metallog, Vol. 19, No. 2, 1965, pp. 101-104, (37516).

McClaren, S. W. and C. R. Foreman, Cryogenic Design Data for Materials Subjected to Uniaxial and Multiaxial Stress Field, LTV Aerospace Corp., Dallas, Texas, Report No. AFML-TR-65-140, May, 1965, (29190)

McGee, R. L., J. E. Campbell and K. L. Carlson, The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures, Battelle Memorial Institute, Columbus, Ohio, WADC Technical Report No. 58-386, November, 1958, (7507).

Nachtigall, A. J., S. J. Klima and J. C. Freche, Fatigue of Liquid Rocket Engine Metals at Cryogenic Temperatures to -452 Degrees F, NASA, Lewis Research Center, Cleveland, Ohio, Technical Note No. D-4274, December, 1967, (48997).

Schwartzberg, F. R., R. D. Keys and M. J. Brown, Determination of Low Temperature Fatigue Properties of Aluminum and Titanium Alloys, Martin Co., Denver, Colorado, Annual Summary Report, NASA CR-55027, July, 1963, (22873).

Witzell, W. E., Fracture Data for Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. GDC-ZZL-67-017, November, 1967, (52334).

A.2.2.1.4 Poisson's Ratio of Titanium Alloys

McClaren, S. W. and C. R. Foreman, Biaxial Strength Characteristics of Selected Alloys in a Cryogenic Environment, LTV Aerospace Corp., Dallas, Texas, Report No. 2-53420/GR-2279, May, 1966, (42163).

Sullivan, T. L., Texture Strengthening and Fracture Toughness of Titanium Alloy Sheet at Room and Cryogenic Temperatures, NASA, Lewis Research Center, Cleveland, Ohio, Technical Note D-4444, May 1968, (51277)

A.2.2.1.5 Elongation and Reduction in Area of Titanium Alloys

Christian, J. L., Mechanical Properties of Titanium and Titanium Alloys at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. MGR-189, Ocotber, 1960, (11856).

Mikheev, U. S., P. F. Koshelav and P. N. Nikitin, "Mechanical Properties of Alloys of the Ti-Ta System at Low Temperatures", Metal Science Heat Treatment, NOS. 9-10, 1969, pp. 679-680, (68406).

Schwartzberg, F. R., R. D. Keys, M. J. Brown and C. L. Reightler, Determination of Low Temperature Fatigue Properties of Aluminum and Titanium Alloys, Martin Co., Denver, Colorado, Annual Summary Report, NASA CR-55027, July, 1963, (22873).

A.2.2.1.6 Torsional Properties of Titanium Alloys

Fahey, N. H., Ultrasonic Determination of Elastic Constants at Room and Low Temperatures, Watertown Arsenal Labs, Mass., Technical Report No. WAL-TR-118.1, April, 1960, (8544).

A.2.2.1.7 Notch Toughness of Titanium Alloys

Bousova, E. A., S. E. Belyayer and G. S. Klimova, "Mechanical Properties of Titanium Alloys at Low Temperatures", Russian Metals, No. 4, 1968, pp. 95-97, (68272).

Carman, C. M. and J. M. Katlin, "Plane Strain Fracture Toughness and Mechanical Properties of 5 Al-2.5-SN ELI and Commercial Titanium Alloys at Room and Cryogenic Temperatures", American Society of Testing Materials, Special Technical Publication No. 432, 1968, (49934).

Christian, J. L. and A. Hurlich, "Mechanical Properties of Titanium Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 13, Plenum Press, Inc., New York, 1968, pp. 318-333, (47515).

Frederick, S. F. and W. D. Hanna, "Fracture Toughness and Deformation of Titanium Alloys at Low Temperatures", Metals Transactions, Vol. 1, February, 1970, pp. 347-352, (65845).

Hendricks, P. L., "Air Force Materials Laboratory Symposium on Light Metals", Light Metal Age, Vol. 23, No. 5-6, June, 1965, pp. 5-6, (37663).

Schwartzberg, F. R., "A Review of Cryogenic Fracture Toughness Behavior", Advances in Cryogenic Engineering, Vol. 12, Plenum Press, Inc., New York, 1967, pp. 458-472, (38040).

Viglione, J. and W. F. Worden, Fracture Toughness Properties of Some Alloy Steels and Aluminum and Titanium Alloys, Naval Air Engineering Center, Aeronautical Material Lab, Philadelphia, Report No. NAEC-AML-2111, March, 1965, (29137).

Witzell, W. E., Fracture Data for Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. GDC-ZZL-67-017, November,11967, (52334).

A.2.2.1.8 Fatigue Properties of Titanium Alloys

Favor, R. J., D. N. Gideon and H. J. Grover, Investigation of Fatigue Behavior of Certain Alloys in the Temperature Range Room Temperature to -423 F, Battelle Memorial Institute, Columbus, Ohio, Technical Report No. WADD TR 61-132, June, 1961, (15663).

Gideon, D. N., R. J. Favor, H. J. Grover and G. M. McClure, "The Fatigue Behavior of Certain Alloys in the Temperature Range from Room Temperature to -423 Degrees F", Advances in Cryogenic Engineering, Vol. 7, Plenum Press, New York, 1962, pp. 503-508, (15385).

Hurlich, A., The Cryogenic Behavior of Titanium, Titanium Metallurgy Course, New York University, New York, September, 1965, (33379).

Keys, R. D. and F. R. Schwartzberg, "Axial Fatigue Testing of Sheet Materials Down to -423°F", Material Research Standards, Vol. 4, No. 5, May, 1964, pp. 222-224, (22996).

Nachtigall, A. [illegible]., S. J. Klima and J. C. Freche, Fatigue of Liquid Rocket [illegible]nes Metals at Cryogenic Temperatures to -452 Degrees F, NASA, Le[illegible]s Research Center, Cleveland, Ohio, Technical Note D-4274, December, 1967, (48997).

Schwartzberg, F. R., R. D. Keys, M. J. Brown,and C. L. Reightler, Determination of Low Temperature Fatigue Properties of Aluminum and Titanium Alloys, Martin Co., Denver, Colorado, Annual Summary Report, NASA CR-55027, July, 1963, (22873).

A.2.2.2 Thermophysical Properties of Titanium Alloys

A.2.2.2.1 Thermal Conductivity of Titanium Alloys

Hertz, J. and D. Knowles, Survey of Thermal Properties of Selected Materials, General Dynamics/Convair, San Diego, Report No. ZZL-65-008, February, 1965, (34723).

Hust, J. G., D. H. Weitzel and R. L. Powell, Thermal Conductivity of Aerospace Alloys at Cryogenic Temperatures, NBS Special Publication 302, September, 1968, (54548).

Rigney, C. J. and L. I. Bochstahler, "The Thermal Conductivity of Titanium Between 20 Degrees and 273 Degrees K", Physical Review, Vol. 83, 1951, pp. 220, (27346).

Wigley, D. A., "Mechanical Properties of Materials at Low Temperatures", Cryogenics, Vol. 8, No. 1, February, 1968, pp. 3-12, (49672).

Ziegler, W. T., J. C. Mullins and S. C. P. Hwa, "Specific Heat and Thermal Conductivity of Four Commercial Titanium Alloys from 20 Degrees to 300 Degrees K", Advances in Cryogenic Engineering, Vol. 8, 1962, pp. 268-277, (13342).

A.2.2.2.2 Specific Heat of Titanium Alloys

Clark, A. F. and R. H. Kropschot, "Low Temperature Specific Heat and Thermal Expansion of Alloys", Bulletin Institut International Du Froid, Annexe 1970-1972, pp. 249-254, (70814).

Lepkowski, W. J. and J. W. Holladay, Report on the Physical Properties of Titanium and Titanium Alloys, Battelle Memorial Institute, Columbus, Ohio, TML Report No. 73, July, 1957, (4953).

Touloukian, Y. S., Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents and Their Oxides, Thermophysical Properties Research Center, Purdue University, Report No. CST-7590, February, 1966, (34238).

Ziegler, W. T., J. C. Mullins and S. C. P. Hwa, "Specific Heat and Thermal Conductivity of Four Commercial Titanium Alloys from 20 Degrees to 300 Degrees K", Advances in Cryogenic Engineering, Vol. 8, Plenum Press, New York, 1962, pp. 268-277, (13342).

A.2.2.2.3 Thermal Expansion of Titanium Alloys

Corruccini, R. J. and J. J. Gniewek, Thermal Expansion of Technical Solids at Low Temperature, NBS Monograph 29, May, 1961, (11486).

Rhodes, B. L., C. E. Moeller, V. Hopkins and T. I. Marx, "Thermal Expansion of Several Technical Metals from 20 Degrees K to 300 Degrees K", Advances in Cryogenic Engineering, Vol. 8, Plenum Press, New York, 1963, pp. 278-286, (13346).

Zakharov, A. and K. Trush, "Thermal Expansion of Metals and Alloys at Low Temperatures", Metalloved, No. 10, October, 1970, pp. 39-41, (85263).

A.2.2.2.4 Density of Titanium Alloys

Lepkowski, W. J. and J. W. Holladay, Report on the Physical Properties of Titanium and Titanium Alloys, Battelle Memorial Institute, Columbus, Ohio, TML Report No. 73, July, 1957, (4953).

A.2.2.3 Electrical Conductivity of Titanium Alloys

Clark, A. F., G. E. Childs and G. H. Wallace, "Low Temperature Electrical Resistivity of Some Engineering Alloys", Advances in Cryogenic Engineering, Vol. 15, Plenum Press, New York, 1970, pp. 85-90, (58031).

Hust, J. G., D. H. Weitzel and R. L. Powell, Thermal Conductivity of Aerospace Alloys at Cryogenic Temperatures, NBS Special Publication 302, September, 1968, (54548).

Rayetskiy, V. M., "Resistivity of Titanium Alloys with Aluminum at 78-373 Degrees K", Physical Metals Metallog, Vol. 23, No. 4, 1967, pp. 186-188, (53788).

A.2.2.4 Magnetic Properties of Titanium Alloys

Lepper, R., E. G. Wolff and G. J. Mills, "A.C. Permeability Studies of Ternary Alloys at Cryogenic Temperatures", Applied Superconductivity Conference, IEEE, Inc., New York, 1972, pp. 461-467, (85497).

Luhman, T. S., R. Taggart and D. H. Polonis, "Magnetic Hysteresis Studies of Superconducting Beta Stabilized Titanium Alloys", Structural Metals, Vol. 6, No. 10, October, 1972, pp. 1055-1060, (82736).

Shibuya, Y. and T. Aomine, "Upper Critical Fields and Magnetization Curves for Ti-U Alloys", Low Temperature Physics and Chemistry, Vol. IIA, Superconductivity, 1967, pp. 490-495, (56095).

A.2.3 Cryogenic Properties of Aluminum Alloys

A.2.3.1 Mechanical Properties of Aluminum Alloys

A.2.3.1.1 Tensile Properties of Aluminum Alloys

Barth, H. A., "Materials for Low and Very Low Temperature Plants", Institut International Du Froid, Paris, 1961, pp. 477-487, (60381).

Campbell, J. E., "Aluminum Alloys for Cryogenic Service", Material Research Standards, Vol. 4, No. 10, October, 1964, pp. 540-548, (28730).

Campbell, J. E., Properties and Applications of Aluminum Alloys at Low Temperatures, ASTM 67th Meeting, Chicago, Paper No. 33, June, 1964, (24677).

Campbell, J. E., Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures, DMIC, Battelle Memorial Institute Columbus, Ohio, Report No. 148, February, 1961, (10528).

Carson, J. M. and J. M. Hawn, Some Properties of Iron, Copper and Selected Aluminum Alloys, Dayton University, Ohio, Research Institute, Report No. UDRI-TR-68-38, September, 1968, (59390).

Christian, J. L. and J. F. Watson, "Mechanical Properties of Several 2000 and 6000 Series Aluminum Alloys", Advances in Cryogenic Engineering, Vol. 10, Plenum Press, New York, 1965, pp. 63-76, (34338).

Christian, J. L. and J. F. Watson, "Mechanical Properties of Several 5000 Series Aluminum Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 7, 1962, pp. 490-499, (11395).

Christian, J. L. and J. F. Watson, "Properties of 7000 Series Aluminum Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 6, 1961, pp. 604-621, (11363).

Coursen, J. W. and J. G. Kaufman, "Notch Toughness of Some Aluminum Alloy Castings at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 12, Plenum Press, New York, 1967, pp. 473-483, (38049).

"Effect of Low Temperatures on Structural Metals", Light Metal Age, Vol. 23, No. 1/2, February, 1965, pp. 14-19, (30706).

Eldridge, E. A. and H. W. Deem, "Report on Physical Properties of Metals and Alloys from Cryogenic to Elevated Temperatures", American Society for Testing Materials, Special Technical Publication No. 296, April, 1961, (10667).

Fushima, K., H. Yonemitsu, H. Okamoto and E. Fukushima, "Tensile Properties of Various Materials at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 15, Plenum Press, New York, 1970, pp. 102-108, (60929).

Hickey, C. F., Mechanical Properties of Titanium and Aluminum Alloys at Cryogenic Temperatures, Watertown Arsenal Labs, Mass., Technical Report WAL TR 340.2/1, March, 1962, (13223).

Johnson, E. W., "Aluminum Alloys-Tough and Ductile Down to -423 Degrees F", Chemical Engineering, Vol. 67, August, 1960, pp. 133-139, (10284).

Kaufman, J. G., "Notch Toughness of Some Aluminum Alloys by Proposed ASTM Recommended Practice", Proceedings American Society of Testing Material, Vol. 65, 1965, pp. 626-640, (38183).

Kaufman, J. G., K. O. Bogardus and E. T. Wanderer, "Tensile Properties and Notch Toughness of Aluminum Alloys at -452 F in Liquid Helium", Advances in Cryogenic Engineering, Vol. 13, Plenum Press, New York, 1968, pp. 294-308, (47122).

Kaufman, J. G. and E. W. Johnson, "Notch Sensitivity of Aluminum Alloy Sheet and Plate at -320 Degrees F Based on Notch Yield Ratio", Advances in Cryogenic Engineering, Vol. 8, Plenum Press, New York, pp. 678-685, (12997).

Kaufman, J. G. and F. G. Nelson, Axial Stress Fatigue Properties of Plain and Welded 5454, 5086, 5083, and 5456 Plate at Room Temperature and -320 Degrees F, Alcoa Research Labs, New Kensington, Pa., Report No. 9-60-24, June, 1960, (9999).

Kaufman, J. G. and E. T. Wanderer, "Tensile Properties and Notch Toughness of Some 7XXX Alloys at -452 Degrees K", Advances in Cryogenic Engineering, Vol. 16, Plenum Press, New York, 1971, pp. 27-36, (65882).

Kieffer, T. F., R. D. Keys and F. R. Schwartzberg, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colorado, Final Report CR-65-70, October, 1965, (31808).

Koshelev, P. F., R. I. Ilina and M. F. Nikitina, "Mechanical Properties of Aluminum Alloys at Low Temperatures", Mashinostr., No. 6, 1968, pp. 86-94, (69909).

Martin, H. L. and A. G. Ingram, "Effects of Low Temperature on Structural Metals", Journal of Metals, Vol. 17, No. 7, July, 1965, p. 735, (31049).

"Materials for Large Cryogenic Structures", Environmental Quarterly, Vol. 12, No. 1, March, 1966, p. 25, (38688).

McClaren, S. W., Cryogenic Design Data on Materials Subjected to Uniaxial and Multiaxial Stress Fields, LTV, Dallas, Texas, Quarterly Progress Report No. 1, May, 1964, (27202).

McClaren, S. W., C. R. Foreman and J. F. Grobinski, Biaxial Strength Characteristics of Selected Alloys in a Cryogenic Environment, LTV Aerospace Corp., Dallas, Texas, Report No. 2-53420/6R-2279, May, 1966, (42163).

McClintock, R. M. and H. P. Gibbons, A Compilation of Mechanical Properties of Materials at Cryogenic Temperatures, NBS Report No. 6064, July, 1959, (4413).

Mikesell, R. P. and R. P. Reed, "The Impact Testing of Various Alloys at Low Temperatures", Advances in Cryogenic Engineering, Vol. 3, Plenum Press, New York, 1960, pp. 316-324, (8908).

Misha, K. H., "Conventional Alloys Solve Cryogenic Problems", Materials Engineering, Vol. 76, No. 2, August 1972, pp. 22-26, (80573).

Nachtigall, A. J., S. J. Klima and J. C. Freche, Fatigue of Liquid Rocket Engine Metals at Cryogenic Temperatures to -452 Degrees F, NASA, Lewis Research Center, Cleveland, Ohio, Technical Note No. D-4274, December, 1967, (48997).

"New High Strength Aluminum Alloys Take Cryogenic Temperatures", Materials Engineering, Vol. 68, No. 1, July, 1968, p. 32, (52168).

"Properties of Alloys for Low Temperature and Cryogenic Service", Metal Progress, Vol. 104, No. 1, June, 1973, p. 124, (86893).

Rice, L. P., J. E. Campbell and W. F. Simmons, "The Tensile Property Evaluation of One 5000 Series Aluminum at the Temperature of Liquid Helium", Advances in Cryogenic Engineering, Vol. 8, 1962, pp. 671-677, (12998).

Schwartzberg, F. R., Selecting Structural Materials for Cryogenic Service, Metals Progress, Vol. 96, No. 1, July, 1969, pp. 52-57, (60845).

Schwartzberg, F. R., R. D. Keys and M. J. Brown, Determination of Low Temperature Fatigue Properties of Aluminum and Titanium Alloys, Martin Co., Denver, Colorado, Annual Summary Report, NASA CR-55027, July, 1963, (22873)

Schwartzberg, F. R. and R. D. Keys, Mechanical Properties of 2000 Series Aluminum Alloys at Cryogenic Temperatures, Martin Co., Denver, Colorado, Report No. R-61-32, October, 1961, (11416).

Schwartzberg, F. R., T. F. Kiefer and R. D. Keys, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colorado, Final Report, NASA CR-59839, October, 1964, (28864).

Sprentak, J. W., M. C. Fontana and A. E. Brooks, "Notched and Unnotched Tensile and Fatigue Properties of Tin Engineering Alloys at 25 Degrees C and -196 Degrees C", Transactions of the American Society of Metals, Vol. 43, 1951, pp. 547-570, (5047).

Uzhik, G. V., "The Low Temperature Strength and Ductility of Metals", Engineering Institute of the Academy of Sciences, USSR, 1957, (13946).

Vishnevsky, C. and E. A. Steigerwald, Plane Strain Fracture Toughness of Some Cryogenic Materials at Room and Subzero Temperatures, 73rd ASTM Meeting, Toronto, Ontario, Canada, Paper No. 496, (72843).

Warren, K. A. and R. P. Reed, Tensile and Impact Properties of Selected Materials from 20 to 300 Degrees K, NBS Monograph No. 63, June, 1963, (17164).

Watson, J. F., "Materials at Cryogenic Temperatures", Materials for Missiles and Spacecraft, McGraw Hill Book Co., New York, 1963, (21060).

Witzell, W. E., Fracture Data for Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. GDC-ZZL-67-017, November, 1967, (52334).

Yang, C. T., "Cryogenic Temperature Dependence of the Yield Strength of High Strength Alloys", Journal of the Engineering Industry, Vol. 88, Ser. B, No. 1, February, 1966, pp. 117-128, (33904).

A.2.3.1.2 Proportional Limit of Aluminum Alloys

Christian, J. L. and J. F. Watson, "Mechanical Properties of Several 5000 Series Aluminum Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 7, Plenum Press, New York, 1962, pp. 490-499, (11395).

Christian, J. L. and J. F. Watson, "Properties of 7000 Series Aluminum Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, 1961, pp. 604-621, (11363).

A.2.3.1.3 Elastic Modulii of Aluminum Alloys

Campbell, J. E., Properties and Applications of Aluminum Alloys at Low Temperatures, ASTM 67th Annual Meeting, Chicago, June, 1964, (24677).

Christian, J. L. and J. F. Watson, "Mechanical Properties of Several 2000 and 6000 Series Aluminum Alloys", Advances in Cryogenic Engineering, Vol. 10, Plenum Press, New York, 1965, pp. 63-76, (34338).

Kiefer, T. F., R. D. Keys and F. R. Schwartzberg, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colorado, Report No. CR-65-70, October, 1965, (31808).

McClaren, S. W., C. R. Foreman and J. F. Grabinski, Biaxial Strength Characteristics of Selected Alloys in a Cryogenic Environment, LTV Aerospace Corp., Dallas Texas, Report No. 2-53420/6R-2279, May, 1966, (42163).

Midgely, P. and R. W. Thackray, The Tensile Properties of Some Structural Materials in the Temperature Range 293 K to 20 K, Rocket Propulsion Establishment, Wescott, England, Report No. RPE-TM-496, February, 1969, (69428).

Nachtigall, A. J., S. J. Klima and J. C. Freche, Fatigue of Liquid Rocket Engine Metals at Cryogenic Temperatures to -452 Degrees F, NASA, Lewis Research Center, Cleveland, Ohio, Technical Note No. D-4274, December, 1967, (48997).

Redmond, J. H. and F. W. Bott, Design Study of AC Motors to Operate in Helium from the Cryogenic Liquid State to Room Temperature Gaseous State, AIAA Propulsion 3rd Joint Specialist Conference, Washington, D. C., July, 1967, Paper No. AIAA67-456, (48362).

Schwartzberg, F. R., R. D. Keys and M. J. Brown, Determination of Low Temperature Fatigue Properties of Aluminum and Titanium Alloys, Martin Co., Denver, Colorado, Annual Summary Report NASA CR-55027, July, 1963, (22873).

Witzell, W. E., Fracture Data for Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. GDC-ZZL-67-017, November, 1967, (52334).

A.2.3.1.4 Poisson's Ratio of Aluminum Alloys

McClaren, S. W., C. R. Foreman and J. F. Grabinski, Biaxial Strength Characteristics of Selected Alloys in a Cryogenic Environment, LTV Aerospace Corp., Dallas, Texas, Report No. 2-53420/6R2279, May, 1966, (42163).

Schwartzberg, F. R., R. D. Keys and T. F. Kiefer, Cryogenic Alloy Screening, Final Report, NASA, Lewis Research Center, Cleveland, Ohio, Report No. NASA-CR-72733, November, 1970, (75142).

A.2.3.1.5 Elongation and Reduction in Area of Aluminum Alloys

Barth, H. A., Permanent Property Changes of Metals Caused by Low Temperatures, 11th International Congress of Refirgeration, Munich, Paper I-17, August, 1963, (18090).

Christian, J. L. and J. F. Watson, "Mechanical Properties of Several 5000 Series Aluminum Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 7, Plenum Press, New York, 1962, pp. 490-499, (11395).

Christian, J. L. and J. F. Watson, "Properties of 7000 Series Aluminum Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, 1961, pp. 604-621, (11363).

Everest, A., "The Behavior of High Magnesium Content Aluminum Alloys at Room and Liquid Hydrogen Temperatures", Advances in Cryogenic Engineering, Vol. 5, Plenum Press, New York, 1960, pp. 385-396, (8990).

Dannelli, A. A. and F. J. Rizzitano, Notched Properties of High Strength Alloys at Various Load Rates and Temperatures, Army Materials Research Agency, Watertown, Mass., Technical Report No. AMRA-TR-66-13, July, 1966, (45416).

Kaufman, J. G. and E. W. Johnson, "New Data on Aluminum Alloys for Cryogenic Applications", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, 1961, pp. 637-649, (11366).

Lightweight Aluminum Casting Alloy Is Useful at Cryogenic Temperatures, NASA Technical Brief No. BG5-10092, April, 1965, (27398).

Midgely, P. and R. W. Thackray, The Tensile Properties of Some Structural Materials in the Temperature Range 293 K to 20 K, Rocket Propulsion Establishment, Westcott, Englend, Report No. RPE-TM-496, February, 1969, (69428).

Schwartzberg, F. R., R. D. Keys, M. J. Brown and C. L. Reightler, Determination of Low Temperature Fatigue Properties of Aluminum and Titanium Alloys, Martin Co., Denver, Colorado, Annual Summary Report NASA CR-55027, July, 1963, (22873).

Schwartzberg, F. R. and R. D. Keys, Mechanical Properties of 2000 Series Aluminum Alloys at Cryogenic Temperatures, Martin Co., Denver, Colorado, Report No. R-61-32, October, 1961, (11416).

A.2.3.1.6 Torsional Properties of Aluminum Alloys

Christian , J. L. and J. F. Watson, "Mechanical Properties of Several 5000 Series Aluminum Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 7, Plenum Press, New York, 1962, pp. 490-499, (11395).

Christian, J. L. and J. F. Watson, "Properties of 7000 Series Aluminum Alloys at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, 1961, pp. 604-621, (11363).

A.2.3.1.7 Notch Toughness of Aluminum Alloys

Campbell, J. E., Properties and Applications of Aluminum Alloys at Low Temperatures, ASTM 67th Annual Meeting, Chicago, June, 1964, Paper, (24677).

Carman, C. M., KC (Fracture Toughness) Determination for Aluminum Alloys, Frankford Arsenal, Metallurgy Research Lab, Philadelphia, 1962, Paper 14, (17378).

Coursen, J. W. and J. G. Kaufman, "Notch Toughness of Some Aluminum Alloy Castings at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 12, Plenum Press, New York, 1967, pp. 478-483, (38049).

Kaufman, J. G., K. O. Bogardus and E. T. Wanderer, "Tensile Properties and Notch Toughness of Aluminum Alloys at -452 F in Liquid Helium", Advances in Cryogenic Engineering, Vol. 13, Plenum Press, New York, 1968, pp. 294-308, (47122).

Kaufman, J. G. and E. T. Wanderer, "Tensile Properties and Notch Toughness of Some 7XXX Alloys at -452 Degrees K", Advances in Cryogenic Engineering, Vol. 16, Plenum Press, New York, 1971, pp. 27-36, (65882).

McClaren, S. W., C. R. Foreman and J. F. Grabinski, Biaxial Strength Characteristics of Selected Alloys in a Cryogenic Environment, LTV Aerospace Corp., Dallas, Texas, Report No. 2-53420/6R-2279, May, 1966, (42163).

Orange, T. W., T. L. Sullivan and F. D. Calfo, Fracture of Thin Sections Containing Through and Part-through Cracks, ASTM STP496 Fracture Toughness Testing at Cryogenic Temperatures Conference, Toronto, Ontario, Canada, June, 1970, (72846).

Schwartzberg, F. R., "A Review of Cryogenic Fracture Toughness Behavior", Advances in Cryogenic Engineering, Vol. 12, Plenum Press, New York, 1967, pp. 458-472, (38050).

Schwartzberg, F. R., "Selecting Structural Materials for Cryogenic Service", Metals Progress, Vol. 96, No. 1, July, 1969, pp. 52-57, (60845).

Viglione, J. and W. F. Worden, Fracture Toughness Properties of Some Alloy Steels and Aluminum and Titanium Alloys, Naval Air Engineering Center, Aeronautical Materials Lab, Philadelphia, Report No. NAEC-AML-2111, March, 1965, (29137).

Watson, J. F. and J. L. Christian, The Effect of Cryogenic Temperatures on the Mechanical Properties of High Strength Sheet Alloys (Nonferrous), General Dynamics/Convair, Report ERR-AN-002, April, 1960, (11854).

Witzell, W. E., Fracture Data for Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. GDC-ZZL-017, November, 1967, (52334).

A.2.3.1.8 Fatigue Properties of Aluminum Alloys

Campbell, J. E., Properties and Applications of Aluminum Alloys at Low Temperatures, 67th ASTM Annual Meeting, Chicago, Paper No. 33, June, 1964, (24677).

Favor, R. J., D. N. Gideon and H. J. Grover, Investigation of Fatigue Behavior of Certain Alloys in the Temperature Range Room Temperature to -423 F, Battelle Memorial Institute, Columbus, Ohio, Report No. WADD TR 61-132, June, 1961, (15663).

Gadeau, R., "Cryogenic Aluminum Alloys", Review of Aluminum, Vol. 39, No. 304, December, 1962, pp. 1355-1369, (16194).

Hartman, E. C. and W. H. Sharp, A Summary of Results of Various Investigations of the Mechanical Properties of Aluminum Alloys at Low Temperatures, NACA, Technical Note No. 843, May, 1942, (17402).

Kaufman, J. G., M. Holt and E. T. Wanderer, "Aluminum Fills Cryogenic Needs", Oil Gas Journal, Vol. 65, No. 50, December, 1967, pp. 118-126, (48330)

Kaufman, J. G. and F. G. Nelson, "Cryogenic Temperatures Up Fatigue Strengths of Al-Mg Alloys", Space Aeronautics, Vol. 38, No. 1, July, 1962, pp. 91-96, (12513).

Nachtigall, A. J., S. J. Klima and J. C. Freche, Fatigue of Liquid Rocket Engine Metals at Cryogenic Temperatures to -452 Degrees F, NASA, Lewis Research Center, Cleveland, Ohio, Technical Note D-4274, December, 1967, (48997).

Schwartzberg, F. R., R. D. Keys, M. J. Brown and C. L. Reightler, Determination of Low Temperature Fatigue Properties of Aluminum and Titanium Alloys, Martin Co., Denver, Colorado, Annual Summary Report NASA CR-55027, July, 1963, (22873).

Schwartzberg, F. R., T. F. Kieffer and R. D. Keys, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colorado, Final Report NASA-CR-59839, October, 1964, (28864).

Spretnak, J. W., M. C. Fontana and A. E. Brooks, "Notched and Unnotched Tensile and Fatigue Properties of Ten Engineering Alloys at 25 Degrees C and -196 Degrees C", Transactions of the American Society for Metals, Vol. 43, 1951, pp. 547-570, (5047).

Uzhik, G. V., "The Low Temperature Strength and Ductility of Metals", Engineering Institute of the Academy of Sciences, USSR, Moscow, 1957, (13946).

Wolff, R. P. and R. A. Dodd, "Fatigue Properties of Some Age-Hardened Alloys", Materials Research Standards, Vol. 3, No. 9, September, 1963, pp. 734-735, (20175).

A.2.3.2 Thermophysical Properties of Aluminum Alloys

A.2.3.2.1 Thermal Conductivity of Aluminum Alloys

Campbell, R. W. and J. E. Browning, "Materials of Construction for Cryogenic Processes", Chemical Engineering, Vol. 74, No. 22, October, 1967, pp. 196-197, (48334).

Dillard, D. S. and K. D. Timmerhaus, Thermal Transport Properties of Selected Solids at Low Temperatures, 16th Annual AICHT Meeting, New York, November, 1967, Paper 30A, (49650).

Eldridge, E. A. and H. W. Deem, Report on Physical Properties of Metals and Alloys from Cryogenic to Elevated Temperatures, ASTM Special Technical Publication No. 296, April, 1961, (10667).

Evaluation of the Thermal Properties of Materials, Avco Corp., Lowell, Mass., Report No. NASA-CR-65979, September, 1966, (52682).

Hertz, J. and D. Knowles, Survey of Thermal Properties of Selected Materials, General Dynamics/Convair, San Diego, Report No. ZZL-65-008, February, 1965, (34723).

Hust, J. G., D. H. Weitzel and R. L. Powell, Thermal Conductivity of Aerospace Alloys at Cryogenic Temperatures, NBS Special Publication No. 302, September, 1968, (54548).

Powell, R. L., Thermophysical Properties of Metals at Cryogenic Temperatures, ASTM Special Technical Publication No. 387, 1966, (36272).

Powell, R. L., J. Hall and H. M. Roder, "Low Temperature Transport Properties of Commercial Metals and Alloys", Journal of Applied Physics, Vol. 31, No. 3, 1960, pp. 496-503, (2296).

Powell, R. W., R. P. Tye and J. Woodman, "The Thermal Conductivity of Pure and Alloyed Aluminum", Proceedings of the 3rd Symposium ASME, Purdue University, March, 1965, pp. 277-288, (26179).

Touloukian, Y. S., Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents, and Their Oxides, Thermophysical Properties Research Center, Purdue University, Report No. CST-7590, February, 1966, (34238).

A.2.3.2.2 Specific Heat of Aluminum Alloys

Clark, A. F. and R. H. Kropschot, "Low Temperature Specific Heat and Thermal Expansion of Alloys", Bulletin du Institut International Du Froid, Annexe 1970-1972, pp. 249-254, (70814).

Hertz, J. and D. Knowles, Survey of Thermal Properties of Selected Materials, General Dynamics/Convair, San Diego, Report No. ZZL-65-008, February, 1965, (34723).

Touloukian, Y. S., Recommended Values of Thermophysical Properties of Eight Alloys, Major Constituents and Their Oxides, Thermophysical Properties Research Center, Purdue University, Report No. CST-7590, February, 1966, (34238).

A.2.3.2.3 Thermal Expansion of Aluminum Alloys

Arp, V., J. H. Wilson, L. Winrich and P. Sikora, "Thermal Expansion of Some Engineering Materials from 20 to 293 Degrees K", Cryogenics, Vol. 2, June, 1962, pp. 230-235, (12732).

Belov, A. K., "Coefficient of Thermal Expansion of Construction Materials at Low Temperatures", Metalloved, No. 4, April, 1968, pp. 20-22, (63674).

Campbell, R. W. and J. E. Urowning, "Materials for Construction in Cryogenic Processes", Chemical Engineering, Vol. 74, No. 22, October, 1967, pp. 196-197, (48334).

Clark, A. F., "Low Temperature Thermal Expansion of Some Metallic Alloys", Cryogenics, Vol. 8, No. 5, October, 1968, pp. 282-289, (54322).

Clark, A. F. and R. H. Kropschot, "Low Temperature Specific Heat and Thermal Expansion of Alloys", Bulletin du Institut International Du Froid, Annexe, 1970-1972, pp. 249-254, (70814).

Horton, J. C., C. F. Smith and R. C. Ruff, Low Temperature Thermal Expansion of Structural Metals, NASA Marshall Space Flight Center, Huntsville, Alabama, Technical Memo No. X-53436, April, 1966, (40641).

Johnson, E. W., "Aluminum Alloys - Tough and Ductile Down to -423 Degrees F", Chemical Engineering, Vol. 67, August, 1960, pp. 133-139, (10284).

Rhodes, B. L., C. E. Moeller, V. Hopkins and T. I. Marx, "Thermal Expansion of Several Technical Metals from 20 Degrees K to 300 Degrees C", Advances in Cryogenic Engineering, Vol. 8, Plenum Press, New York, 1963, pp. 278-286, (13346).

Valentich, J., "New Values for Thermal Coefficients", Production Engineering, Vol. 36, No. 15, July, 1965, pp. 63-71, (30601)

Zakharov, A. and K. Trush, "Thermal Expansion of Metals and Alloys at Low Temperatures", Metalloved, No. 9-10, September, 1970, pp. 853-855, (85263).

A.2.3.2.4 Density of Aluminum Alloys

Zuchs, C. F., H. E. Thompson and A. R. Smith, The Experimental Measurement of Thermal Conductivity, Specific Heats and Densities of Metallic, Transparent and Protective Materials, Part I, Battelle Memorial Institute, Report No. TR-6145-1, February, 1951, (46127).

Touloukian, Y. S., Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents and Their Oxides, Thermophysical Properties Research Center, Purdue University, Report No. CST-7590, February, 1966, (34238).

A.2.3.3 Electrical Conductivity of Aluminum Alloys

Clark, A. F., G. E. Childs and G. H. Wallace, "Low Temperature Electrical Resistivity of Some Engineering Alloys", Advances in Cryogenic Engineering, Vol. 15, Plenum Press, New York, 1970, pp. 85-90, (58031).

Hust, J. G., R. L. Powell and D. H. Weitzel, Thermal Conductivity, Electrical Resistivity and Thermopower of Aerospace Alloys from 4 to 300 K, NBS Report No. 9732, June, 1969, (60655).

Milek, J. T. and S. J. Welles, Chemical Composition and Electrical Resistivity of Aluminum Alloys, Hughes Aircraft Co., Culver City, California, Report No. DS-161, April, 1969, (62104).

Powell, R. L., Thermophysical Properties of Metals at Cryogenic Temperatures, ASTM Special Technical Publication No. 387, 1966, (36272).

Powell, R. L., J. Hall and H. M. Roder, "Low Temperature Transport Properties of Commercial Metals and Alloys", Journal of Applied Physics, Vol. 31, No. 3, 1970, pp. 496-503, (2296).

A.2.3.4 Magnetic Properties of Aluminum Alloys

Blythe, H. J., T. M. Holden and M. Dixon, "The Magnetic and Thermal Properties of Some Aluminum-Rich Alloys", Philosophy Magazine, Vol. 11, No. 110, February, 1965, pp. 235-250, (27393).

Dralle, A. V. and J. Moore, Magnetic Properties of Materials, Goddard Space Flight Center, Greenbelt, Md., NASA N66 23443, 1965, (38185).

A.3 Cryogenic Properties of Steels

A.3.1 Mechanical Properties of Steels

A.3.1.1 Tensile Properties of Steels

Abbott, W. K., "Low Temperature Properties of Austenitic Ductile Iron", Advances in Cryogenic Engineering, Vol. 8, Plenum Press, New York, 1962, pp. 654-660, (12996).

Brickner, K. G., "Selection of Stainless Steels for Cryogenic Service", Cryogenic Industrial Gases, Vol. 4, No. 9, September, 1969, pp. 30-32, (61746).

Brickner, K. G., "Stainless Steels for Room and Cryogenic Temperatures", Metals Engineering Quarterly, Vol. 8, May, 1968, pp. 1-29, (57684).

Campbell, R. W. and J. E. Browning, "Materials of Construction for Cryogenic Processes", Chemical Engineering, Vol. 74, No. 22, October, 1967, (48334).

Campbell, J. E. and L. P. Rice, Properties of Some Precipitation-Hardening Stainless Steels and Low-Alloy High-Strength Steels at Very Low Temperatures, ASTM Special Technical Publication No. 287, 1961, (25489).

Christian, J. L., Evaluation of Materials and Test Methods at Cryogenic Temperatures, General Dynamics/Astronautics, San Diego, Report No. ERR-AN-400, December, 1963, (40145).

Christian, J. L., Mechanical Properties of High Strength Sheet Materials at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. ERR-AN-255, November, 1962, (16854).

Christian, J. L., Mechanical Properties of Type 202 Stainless Steel at Cryogenic Temperatures, General Dynamics/Convair, San Diego, Report No. MGR-298, March, 1962, (14158).

Christian, J. L., J. E. Chafey, A. Hurlich and J. F. Watson, "A Study of Brittle Fracture in Cryogenic Alloys", Metal Progress, Vol. 83, No. 5, May, 1963, pp. 103-106, (18519).

Christian, J. L., J. E. Chafey, A. Hurlich and J. F. Watson, "Structural Alloys for Cryogenic Service", Metals Progress, Vol. 83, No. 3, 1963, pp. 101-104, (21153).

"Cryogenic Materials Data Aid Design and Selection", Product Engineering, Vol. 37, No. 13, June, 1966, pp. 40-44, (37573).

Death, F. J. and H. M. Long, "The Low Temperature Mechanical Properties of Some Selected Austenitic Manganese Steels", Advances in Cryogenic Engineering, Vol. 5, Plenum Press, New York, 1960, pp. 421-429, (8993).

Desisto, T. S., "Low Temperature Charpy, True Stress-Strain, and Notched Tensile Properties of Bare and Weld Deposits of AISI Types 301, 310, 316 and 347 Stainless Steels", ASTM Proceedings, No. 62, 1963, pp. 756-764, (27757).

Desisto, T. S., Low Temperature Mechanical Properties of Base and Weld Deposits of Selected Austenitic Stainless Steels, Army Materials Research Agency, Watertown, Mass., Technical Report No. AMRA-TR-63-08, July, 1963, (18452).

Desisto, T. S. and L. C. Carr, "Low Temperature Mechanical Properties of 300 Series Stainless Steel and Titanium", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, 1961, pp. 577-586, (11360).

Emerging Aerospace Materials, Air Force Materials Lab, Wright-Patterson AFB, Ohio, Technical Report No. 65-114, April, 1965, (41875).

Everhart, J. L., "How to Select Steels for Low Temperature Service", Material Methods, Vol. 35, No. 800, January, 1952, pp. 75-79, (73).

Fushima, K., H. Yonemitsu, H. Okamoto and E. Fukushima, "Tensile Properties of Various Materials at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 15, Plenum Press, New York, 1970, pp. 102-108, (60929).

Gindin, I. A., M. B. Lazareva and A. S. Nikislov, et Al., "Mechanical Properties of Sturctural Alloys at Low Temperatures", Metalloved, No. 5, May, 1964, pp. 44-46, (40746).

Glasier, L. F., Design Allowable Tensile Yield Strength Data, Aerojet-General Corp., Sacramento, Calfironia, Report No. 63 538, September, 1963, (24131).

Guntner, C. J. and R. P. Reed, "Martensitic Transformation Products and Mechanical Properties of Austenitic Stainless Steels at Low Temperatures", Advances in Cryogenic Engineering, Vol. 7, Plenum Press, New York, 1962, pp. 500-502, (13486).

Guntner, C. J. and R. P. Reed, "Mechanical Properties of Four Austenitic Stainless Steels at Temperatures Between 300 Degrees and 20 Degrees K", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, 1961, pp. 565-576, (11359).

Hall, E. R., Tensile and Impact Properties of Cast Stainless Steels at Cryogenic Temperatures, ASTM Special Technical Publication 302, 1961, (13214).

Hefferman, J. D., "Nine Percent Nickel Steel Holds Helium at Minua 320 Degrees F", Chemical Engineering, Vol. 69, No. 21, October, 1962, pp. 210-212, (14062).

Hickel, R. O., D. F. Johnson and R. H. Kemp. "A Summary of the Behavior of Materials at Cryogenic Temperatures", Metals Engineering Quarterly, Vol. 3, No. 2, May, 1963, pp. 18-28, (19718).

Hoke, J. H., P. G. Mabus and G. N. Goller, "Mechanical Properties of Stainless Steels at Subzero Temperatures", Metals Progress, Vol. 55, 1949, pp. 643-648, (89).

Iannelli, A. A. and F. J. Rizzitano, Notched Properties of High Strength Alloys at Various Load Rates and Temperatures, Army Materials Research Agency, Watertown, Mass., Technical Report No. AMRA-TR-66-13, July, 1966, (45416).

Ishizaka, Y., "Recent Developments in Low Temperature Service Steel Plates", Chemical Economics Engineering Review, Vol. 2, No. 4, 1970, pp. 21026, (85123).

Keay, L. K., "Nine Percent Nickel Steel in Low Temperature Service", Welding and Metal Fabrication, Vol. 30, No. 9, September, 1962, pp. 365-367, (16742).

Kiefer, T. F., R. D. Keys and F. R. Schwartzberg, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colorado, Final Report CR-65-70, October, 1965, (31808).

Klouman, G. H., "Special Purpose and High Strength Steels", Chemical Engineering Progress, Vol. 60, No. 7, July, 1964, pp. 100-106, (23300).

Kovneristyi, Yu. K., "Structure and Properties of Steels Used at Cryogenic Temperatures", Metalloved., No. 9, 1969, (69425).

Kropschot, R. H., "The Mechanical Properties of Materials in Cryogenic Environments", Applied Cryogenic Engineering for Ballistic Missiles and Space Vehicles, John Wiley and Sons, Inc., New York, 1962, pp. 44-59, (12261).

Kropschot, R. H., "The Mechanical Properties Testing Program at the NBS-AEC Cryogenic Engineering Laboratory", Advances in Cryogenic Engineering, Vol. 1, Plenum Press, New York, 1960, pp. 235-241, (2564).

Kropschot, R. H. and W. F. Graham, Mechanical Properties of the Austenitic Stainless Steels at Low Temperatures, NBS Report No. 5009, August, 1956, (12692).

Kropschot, R. H., R. M. McClintock and D. A. Van Gundy, "Mechanical Properties of Some Engineering Materials Between 20 Degrees K and 300 Degrees K", Advances in Cryogenic Engineering, Vol. 2, Plenum Press, New York, 1960, pp. 93-99, (8844).

Kula, E. B. and C. F. Hickey, Evaluation of Maragin Steel at US Army Materials Research Agency, AFSC 3rd Maragin Steel Project Review, Dayton, Ohio, July, 1963, (27020).

Lismer, R. E., "The Properties of Some Metals and Alloys at Low Temperatures", Journal of the Institute of Metals, Vol. 89, No. 5, 1961, pp. 145-161, (9825).

Low Temperature and Cryogenic Steels, U.S. Steel Corporation, Materials Manual ADUSS 01-1206, February, 1966, (34315).

"Low Temperature and Cryogenic Steels, How to Choose, Use and Weld Them", Welding Design and Fabrication, Vol. 37, April, 1964, pp. 51-66, (22658).

Maiden, C. J., Some Investigations of the Dynamic Strength of Low Carbon Steels, Canadian Armament Research Development Establishment, Technical Memo No. CARDE-AB-58, March, 1960, (17206).

Martin, H. L., Effects of Low Temperatures on Structural Metals, NASA Special Publication No. SP-5012, December, 1964, (24746).

Martin, H. L. and A. G. Ingram, "Effects of Low Temperature on Structural Metals", Journal of Metals, Vol. 17, No. 7, July, 1965, p. 735, (31049).

Martin, H. L., P. C. Miller, A. G. Ingram and J. E. Campbell, The Effects of Low Temperatures on the Mechanical Properties of Structural Metals, Battelle Memorial Institute, Columbus, Ohio, Report No. NASA-SP-5012, 1968, (45671).

"Materials for Large Cryogenic Structures", Environmental Quarterly, Vol. 12, No. 1, March, 1966, (38688).

McClintock, R. M. and H. P. Gibbons, A Compilation of Mechanical Properties of Materials at Cryogenic Temperatures, NBS Report No. 6064, July, 1959, (4413).

McClintock, R. M. and H. P. Gibbons, Mechanical Properties of Structural Materials at Low Temperatures, A Compilation from the Literature, NBS Monograph No. 13, June, 1960, (9176).

McGee, R. L., et al., "How Low Temperature Affects Nine High Strength Alloys", Materials Design Engineering, Vol. 5, 1959, pp. 106-107, (7541).

McGee, R. L., J. E. Campbell, R. L. Carlson, et al., The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures, Battelle Memorial Institute, Columbus, Ohio, WADC Report No. 58-386, November, 1958, (7507).

Miska, K. H., "Conventional Alloys Solve Cryogenic Problems", Materials Engineering, Vol. 76, No. 2, August, 1972, (80573).

Modl, E. K., "Austenitic Cast Irons for High and Low Temperatures", Subzero Technical Review, Vol. 49, No. 2, 1967, pp. 116-126, (50716).

"Nickel Steel for Low Temperature Applications", Machinery, Vol. 96, January, 1960, p. 183, (27327).

Parker, C. M. and J. W. Sullivan, "How to Select Low Temperature Steels", Machinery Design, Vol. 36, No. 1, January, 1964, pp. 100-111, (21684).

Parker, C. M., J. W. Sullivan, "Steel for Cryogenic Environments Properties-Selection-Uses", Cryogenic Engineering News, Vol. 1, No. 1, August, 1965, pp. 33-38, (31591).

Parker, C. M. and J. W. Sullivan, "Steels for Low Temperatures", Industrial Engineering Chemistry, Vol. 55, No. 5, May, 1963, pp. 18-29, (15758).

"Properties of Alloys for Low Temperature and Cryogenic Service", Metal Progress, Vol. 104, No. 1, June, 1973, (86893).

Rowden, S., "Engineering Steels and Alloys for Low Temperature Service", Engineering Material Design, Vol. 5, March, 1962, pp. 191-196, (25114).

Swenson, C. A., "The Compressive Strengths of Some Technical Metals Between 4.2 Degrees and 300 Degrees K", Advances in Cryogenic Engineering, Vol. 1, Plenum Press, New York, 1960, pp. 251-254, (4816).

"Table of Typical Properties of Wrought Stainless Steel", Metals Progress, Vol. 92, No. 2, August, 1967, pp. 106-109, (46056).

"Toughness at Low Temperatures Offered by Nickel Steels", Chemical Processing, Vol. 24, June, 1961, pp. 43-45, (19676).

"Typical Properties of Wrought Stainless Steels", Metal Progress, Vol. 104, No. 1, June, 1973, pp. 32-37, (86890).

Viglione, J. and W. F. Worden, Fracture Toughness Properties of Some Alloy Steels and Aluminum and Titanium Alloys, Naval Air Engineering Center, Aeronautical Materials Lab, Philadelphia, Report No. NAEC-AML-2111, March, 1965, (29137).

Warren, K. A. and R. P. Reed, Tensile and Impact Properties of Selected Materials From 20 to 300 Degrees K, NBS Monograph No. 63, June, 1963, (17164).

Watson, J. F. and J. L. Christian, Low Temperature Properties of Cold-Rolled AISI Types 301, 302, 304 ELC and 310 Stainless Steel Sheet, ASTM Special Technical Publication No. 287, 1960, (7963).

Watson, J. F. and J. L. Christian, The Effect of Cryogenic Temperatures on the Mechanical Properties of High Strength Sheet Alloys, General Dynamics/Convair, San Diego, Report No. ERR-AN-003, May, 1960, (14148).

Weleff, W., W. F. Emmons and H. S. McQueen, "Shear Strength of Several Alloys at Liquid Hydrogen Temperatures", Advances in Cryogenic Engineering, Vol. 10, Plenum Press, New York, 1965, pp. 50-55, (23923).

Wigley, D. A., "Mechanical Properties of Materials at Low Temperatures", Cryogenics, Vol. 8, No. 1, February, 1968, pp. 3-12, (29672).

Witzell, W. E. and N. R. Adsit, "Temperature Effects on Fracture", Fracture, An Advanced Treatise, Vol. 4, Academic Press, Inc., New York, 1969, pp. 69-112, (63136).

Yang, C. T., Cryogenic Temperature Dependence on the Yield Strength of High-Strength Alloys, ASME Paper No. 65-PROD-14, June, 1965, (29898).

A.3.1.2 Proportional Limit of Steels

Hoke, J. H., P. G. Mabus and G. N. Goller, "Mechanical Properties of Stainless Steels at Subzero Temperatures", Metal Progress, Vol. 55, 1949, pp. 643-648, (89).

A.3.1.3 Elastic Modulii of Steels

Armstrong, P. E. and D. T. Eash, "Simultaneous Measurement of Youngs and the Shear Modulus at Low Temperatures", Advances in Cryogenic Engineering, Vol. 14, Plenum Press, New York, 1969, pp. 64-70, (52711).

Fahey, N. H., Ultrasonic Determination of Elastic Constants at Room and Low Temperatures, Watertown Arsenal Labs, Mass., Technical Report No. WAL-TR-118.1/1, April, 1960, (8544).

Gudkov, S. I., Mechanical Properties of Steel at Low Temperatures, Translation No. FTD-HT-23-624-68, Wright-Patterson AFB, Ohio, June, 1969, (66379).

Haskins, J. F., Measurement of the Elastic Properties of 300 Series Stainless Steels at Cryogenic Temperatures by Ultrasonic Techniques, General Dynamics/Astronautics, San Diego, Report No. ERR-AN-055, April, 1961, (12826).

Kovneristyi, Yu. K., "Structure and Properties of Steels Used at Cryogenic Temperatures", Metalloved., No. 9-10, 1969, pp. 683-695, (69425).

A.3.1.4 Poisson's Ratio of Steels

Fahey, N. H., Ultrasonic Determination of Elastic Constants at Room and Low Temperatures, Watertown Arsenal Labs, Mass, Technical Report No. WAL-TR-118.1/1, April, 1960, (8544).

Haskins, J. F., Measurement of the Elastic Properties of 300 Series Stainless Steels at Cryogenic Temperatures by Ultrasonic Techniques, General Dynamics / Astronautics, San Diego, Report No. ERR-AN-055, April, 1961, (12826).

A.3.1.5 Elongation and Reduction in Area of Steels

Death, F. S. and H. M. Long, "The Low Temperature Mechanical Properties of Some Selected Austenitic Manganese Steels", Advances in Cryogenic Engineering, Vol. 5, Plenum Press, New York, 1960, pp. 421-429, (8993).

Drobnjak, D. J. and J. G. Parr, "Low Temperature Tensile Properties and Notch Ductility of Low Carbon Steel Sheet", Metals Engineering Quarterly, Vol. 9, No. 4, November, 1969, pp. 57-59, (69363).

Guntner, C. J. and R. P. Reed, "Mechanical Properties of Four Austenitic Stainless Steels at Temperatures Between 300 Degrees and 20 Degrees K", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, 1961, pp. 567-576, (11359).

Iannelli, A. A. and F. J. Rizzitano, Notched Properties of High Strength Alloys at Various Load Rates and Temperatures, Army Materials Research Agency, Watertown, Mass., Technical Report No. AMRA-TR-66-13, July, 1966, (45416).

Lismer, R. E., "Properties of Metals at Low Temperatures", Machine Design, Vol. 33, No. 6, March, 1961, pp. 182-187, (10009).

"Table of Typical Properties of Wrought Stainless Steels", Metal Progress, Vol. 92, No. 2, August, 1967, pp. 106-109, (46046).

A.3.1.6 Torsional Properties of Steels

Fahey, N. H., Ultrasonic Determination of Elastic Constants at Room and Low Temperatures, Watertown Arsenal Labs, Mass., Technical Report No. WAL-TR-118.1/1, April, 1960, (8544).

Kropschot, R. H., R. M. McClintock and D. A. Van Gundy, "Mechanical Properties of Some Engineering Materials between 20 Degrees K and 300 Degrees K", Advances in Cryogenic Engineering, Vol. 2, Plenum Press, New York, pp. 93-99, (8844).

Mima, G. and S. Hori, "Torsional Deformation Characteristics of Low Carbon Steel at Low Temperatures", Technological Representative, Osaka University, Vol. 16, March, 1966, pp. 345-352, (40766).

A.3.1.7 Notch Toughness of Steels

Guntner, C. J. and R. P. Reed, "Mechanical Properties of Four Austenitic Stainless Steels at Temperatures Between 300 Degrees and 20 Degrees K", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, 1961, pp. 565-576, (11359).

Hodge, J. M., Steels of Improved Fracture Toughness, ASTM Special Technical Publication No. 302, March, 1962, pp. 96-112, (14665).

"Nine Percent Nickel for Low Temperatures", British Chemical Engineering, Vol. 7, June, 1962, p. 442, (25120).

Schwartzberg, F. R., "A Review of Cryogenic Fracture Toughness Behavior", Advances in Cryogenic Engineering, Vol. 12, Plenum Press, New York,11967, pp. 458-472, (38050).

Shoemaker, A. K. and S. T. Rolfe, The Static and Dynamic Low Temperature Crack-Toughness Performance of Seven Structural Steels, U.S. Steel Corp., Monroeville, Pa., Report No. ARL-B-63302, November, 1968, (72033).

Susukida, H., T. Ando and I. Tsuji, Characteristics of 9 Percent Nickel Steel for Low Temperature Service, Mitsubichi Heavy Industries, Tokyo, Technical Bulletin MTB 010053, October, 1967, (51242).

Viglione, J. and W. F. Worden, Fracture Toughness Properties of Some Alloy Steels and Aluminum and Titanium Alloys, Naval Air Engineering Center, Aeronautical Materials Lab, Philadelphia, Report No. NAWC-AML-2111, March 1965, (29137).

Visheysky, C. and E. A. Steigerwald, Influence of Alloying Elements on the Toughness of Low Alloy Martensitic High Strength Steels, TRW, Inc., Cleveland, Ohio, Report No. ER-7217-1-AMMRC-CR-68-09(F), November, 1968, (60562).

A.3.1.8 Fatigue Properties of Steels

Barron, R. F., "Low Temperature Properties of Engineering Materials", Machine Design, Vol. 32, March, 1960, pp. 189-195, (10356).

Brickner, K. G., "Stainless Steels for Room and Cryogenic Temperatures", Materials Engineering Quarterly, Vol. 8, May, 1968, pp. 1-29, (57684).

"Cryogenic Materials Data Aid Design and Selection", Product Engineering, Vol. 37, No. 13, June, 1966, pp. 40-44, (37573).

Fushimi, K., H. Okamoto and K. Fukushima, "Testings of Strength of Materials at Cryogenic Temperatures", Cryogenic Engineering, Vol. 5, No. 2, 1970, pp. 105-112, (65749).

Gideon, D. N., R. J. Favor, A. Koppenhafer and H. J. Grover, Investigation of Notch Fatigue Behavior of Certain Alloys in the Temperature Range of Room Temperature to -423 Degrees F, Battelle Memorial Institute, Columbus, Ohio, Technical Report ASD-TDR-62-351, August, 1962, (14557).

Hurlich, A. and W. G. Scheck, Evaluation and Application of Stainless Steels in Cryogenic Service, ASTM Special Technical Publication No. 369, 1965, (44534).

Kikukawa, M., M. Jono, T. Kamata and T. Nakano, "Low-Cycle Fatigue Properties of Steels at Low Temperatures", Proceedings of the Japanese Congress of Materials Research, Vol. 13, 1970, pp. 69-72, (85216).

Ohuchida, H., "Fatigue Strength of Notched Specimens at Low Temperatures", Bulletin of JSME, Vol. 11, April, 1968, pp. 220-228, (58153).

Schwartzberg, F. R., T. F. Kiefer and R. D. Keys, Determination of Low Temperature Fatigue Properties of Structural Metal Alloys, Martin Co., Denver, Colorado, Report No. CR-64-74, October, 1964, (23894).

Susukida, H., T. Ando and I. Tsiji, Characteristics of 9 Percent Nickel Steel for Low Temperature Service, Mitsubishi Heavy Industries, Tokyo, Technical Bulletin MTB 010053, October, 1967, (51242).

A.3.2 Thermophysical Properties of Steels

A.3.2.1 Thermal Conductivity of Steels

Brickner, K. G., "Stainless Steels for Room and Cryogenic Temperatures", Metals Engineering Quarterly, Vol. 8, May, 1968, pp. 1-29, (57684).

Chari, M. S. R. and J. DeNobel, "Thermal Conductivity of Some Non-Superconducting Alloys at Low Temperatures", Communications from Kammerlingh Onnes Lab, No. 115C, 1959, (8525).

Hust, J. G. and L. L. Sparks, Thermal Conductivity Standard Reference Materials from 4 to 300 K, NBS Report No. 9786, February, 1971, (70565).

Low Temperature and Cryogenic Steels, U.S. Steel Corp., Pittsburgh, Pa., Materials Manual ADUSS 01-1206, February, 1966, (34315).

Powell, R. L., Thermophysical Properties of Metals at Cryogenic Temperatures, ASTM Special Technical Publication No. 387, 1966, (36272).

Probert, D., "Heat Transport in a Stainless Steel at Very Low Temperatures", Nature, Vol. 201, 1964, pp. 283-284, (22867).

A.3.2.2 Specific Heat of Steels

Brickner, K. G., "Stainless Steels for Room and Cryogenic Temperatures", Materials Engineering Quarterly, Vol. 8, May, 1968, pp. 1-29, (57684).

Corruccini, R. J., "Properties of Materials at Low Temperatures", Chemical Engineering Progress, Vol. 53, No. 6, 1957, pp. 262-267, (3891).

Dillard, D. S. and K. D. Timmerhaus, Thermal Transport Properties of Selected Solids at Low Temperatures, AICHE 16th Annual Meeting Paper No. 30A, November, 1967, (49650).

Du Chatenier, F. J., "Specific Heat Capacity of a Stainless Steel", Physica, Vol. 31, No. 7, July, 1965, pp. 1061-1062, (30864).

Hertz, J. and D. Knowles, Survey of Thermal Properties of Selected Materials, General Dynamics/Convair, San Diego, Report No. ZZL-65-008, February, 1965, (34723).

Low Temperature and Cryogenic Steels, U.S. Steel Corp., Pittsburgh, Pa., Materials Manual ADUSS 01-1206, February, 1966, (34315).

Mazur, J. and W. Zacharko, "The Specific Heat of Carbon Steels at Helium Temperatures", Acta Physica Polonia, Vol. 32, No. 3, Spetember, 1967, pp. 501-514, (49754).

Zoller, P., P. R. Dicher and J. R. Dillinger, "Anamolous Low Temperature Specific Heat of Austenitic Stainless Steels", Journal of Applied Physics, Vol. 40, No. 4, March, 1969, pp. 1964-1966, (59924).

A.3.2.3 Thermal Expansion of Steels

Abbott, W. K., "Low Temperature Properties of Austenitic Ductile Irons", Advances in Cryogenic Engineering, Vol. 8, Plenum Press, New York, 1963, pp. 654-660, (12996).

Campbell, R. W. and J. E. Browning, "Materials of Construction for Cryogenic Processes", Chemical Engineering, Vol. 74, No. 22, October, 1967, (48334).

Corruccini, R. J. and J. J. Gniewek, Thermal Expansion of Technical Solids at Low Temperatures, NBS Monograph No. 29, May, 1966, (11486).

Horton, J. C., C. F. Smith and R. C. Ruff, Low Temperature Thermal Expansion of Structural Metals, NASA, Marshal Space Flight Center, Huntsville, Alabama, Technical Memo No. X-53436, April, 1966, (40641).

Johnston, H. L. and H. W. Altman, "Coefficients of Thermal Expansion of Alloys at Low Temperatures", Journal of Chemical Engineering Data, Vol. 10, No. 3, July, 1965, pp. 241-242, (29823).

Johnston, H. L., R. W. Powers and H. W. Altman, "Accurate Measurement of Certain Physical Properties Down to 20 Degrees K", Advances in Cryogenic Engineering, Vol. 1, Plenum Press, New York, 1960, pp. 267-269, (2952).

Loeb, M. B., "Thermal Contraction Graphs for Cryogenic Temperatures", Chemical Engineering, Vol. 77, No. 13, June, 1970, (65622).

Schwartzberg, F. R., "Selecting Structural Materials for Cryogenic Service", Metal Progress, Vol. 96, No. 1, July, 1969, pp. 52-57, (60845).

A.3.2.4 Density of Steels

Haskins, J. F., Measurement of the Elastic Properties of 300 Series Stainless Steels at Cryogenic Temperatures by Ultrasonic Techniques, General Dynamics/Astronautics, San Diego, Report No. ERR-AN-055, April, 1961, (12826).

Lucks, C. F. and H. W. Deem, Thermal Properties of Thirteen Metals, ASTM Special Technical Publication No. 227, 1958, (8589).

Lucks, C. F., H. B. Thompson, A. R. Smith, et al., The Experimental Measurement of Thermal Conductivities, Specific Heats, and Densities of Metallic, Transparent and Protective Materials, Battelle Memorial Institute, Columbus, Ohio, Report No. TR-6145-1, February, 1951, (46127).

A.3.3 Electrical Conductivity of Steels

Clark, A. F., G. E. Childs and G. H. Wallace, "Low Temperature Electrical Resistivity of Some Engineering Alloys", Advances in Cryogenic Engineering, Vol. 15, Plenum Press, New York, 1970, pp. 85-90, (58031).

Grigsby, D. L., Electrical Resistivity of Selected Materials, Electronic Properties Information Center, Culver City, California, Report No. 44, December, 1966, (54062).

Koval, Yu. N., P. V. Titan and L. G. Khandros, "Variation in the Electrical Resistivity of Steel at Temperatures Below Room Level", Physical Metals Metallographer, Vol. 27, No. 5, May, 1969, (71172).

Milek, J. T., Electrical and Magnetic Properties of the 300 Series Stainless Steel, Electronic Properties Information Center, Culver City, California, Report No. IR-3, July, 1965, (33847).

Stutius, W. and J. R. Dillinger, "Magnetic and Thermal Properties of Some Austenitic Stainless Steels at Low Temperatures", Journal of Applied Physics, Vol. 44, No. 6, June, 1973, pp. 2887-2888, (86863).

A.3.4 Magnetic Properties of Steels

Brechna, H., Materials in Electromagnets and their Properties, Stanford Linear Accelerator Center, Stanford University, California Report No. SLAC-PUB-320, 1967, (45987).

Droll, P. W. and E. J. Lufer, Magnetic Properties of Selected Space-Craft Materials, NASA, Ames Research Center, Moffett Field, California, Technical Memo No. X-60414, 1967, (55035).

Efferson, K. R. and W. J. Leonard, Magnetic Properties of Some Structural Materials Used in Cryogenic Applications, Oak Ridge National Lab, Tennessee, Report No. ORNL-4150, September, 1967, (51283).

Flansburg, L. D. and N. Hershkowitz, "Magnetism in Austenitic Stainless Steels", Journal of Applied Physics, Vol. 41, No. 10, September, 1970, pp. 4082-4086, (66924).

Guntner, C. J. and R. P. Reed, "Mechanical Properties of Four Austenitic Stainless Steels at Temperatures Between 300 Degrees and 20 Degrees K", Advances in Cryogenic Engineering, Vol. 6, Plenum Press, New York, 1961, pp. 565-576, (11359).

Larbalestier, D. C. and H. W. King, "Austenitic Stainless Steels at Cryogenic Temperatures. 1 - Structural Stability and Magnetic Properties", Cryogenics, Vol. 13, No. 3, March, 1973, pp. 160-180, (86316).

Salinger, G. L. and J. C. Wheatley, "Magnetic Susceptibility of Materials Commonly Used in the Construction of Cryogenic Apparatus", Review of Scientific Instrumentation, Vol. 32, No. 7, July, 1961, pp. 872-874, (12728).

A.4 Cryogenic Properties of Polymers

A.4.1 Mechanical Properties of Polymers

A.4.1.1 Tensile Properties of Polymers

Armeniades, C. D., I. Kuriyama, J. M. Roe and E. Baer, Mechanical Behavior of Polyethylene Terephthalate at Cryogenic Temperatures, Case Institute of Technology, Cleveland, Ohio, Report No. NASA-CR-88270, 1966, (48857).

Bringer, R. P., Fluorocarbon Plastics Under the Influence of Unusual Environmental Conditions, Society of Aerospace Materials and Process Engineers National Symposium, St. Louis, May, 1962, Paper, (15395).

Brink, N. O., Determination of the Performance of Plastic Laminates Under Cryogenic Temperatures, Narmco Research and Development, San Diego, Report No. ASD-TDR-62-794, August, 1962, (15516).

Brink, N. O., Mechanical Behavior of Reinforced Plastics at Cryogenic Temperatures, Narmco Research and Development, San Diego, Paper, (21143).

Chamberlain, D. W., "Tensile Fatigue Testing at Temperatures Down to 20 Degrees K", Advances in Cryogenic Engineering, Vol. 9, Plenum Press, New York, 1963, pp. 131-138, (17403).

Chamberlain, D. W., B. R. Lloyd and R. L. Tennent, Determination of the Performance of Plastic Laminates at Cryogenic Temperatures, Narmco Research and Development, San Diego, Report No. ASD-TDR-62-794, March, 1964, (23324).

Evans, D., R. Sheldon and G. B. Stapleton, Properties of Thermoplastic Materials at Low Temperatures, 15th Cryogenic Engineering Conference, Los Angeles, California, June, 1969, Paper J-5, (60943).

Hargreaves, R. and D. H. Tantam, "Performance of Some Plain Bearing Materials Under Boundary Conditions at Low Temperatures", Proceedings of the Institute of Mechanical Engineers, Vol. 175, No. 20, 1961, pp. 941-954, (15506).

Hauck, J. E., "Epoxy Plastics", Materials Design in Engineering, Vol. 61, No. 1, January, 1965, pp. 111-122, (25905).

Hertz, J., Tensile Testing of Adlock 851, Adlock PG-LA and Adlock EG-11A-81A From -423 Degrees F to 78 Degrees F, General Dynamics/Convair, San Diego, Report MRG 237, July, 1961, (11849).

Hertz, J., Tensile Testing of Conolon 506 at Room and Sub-Zero Temperatures, General Dynamics/Convair, San Diego, Report MRG-120, December, 1959, (11852).

Hertz, J., "The Effect of Cryogenic Temperatures on the Mechanical Properties of Reinforced Plastic Laminates", SPE Journal, Vol. 21, February, 1965, pp. 181-189, (28613).

"How Plastics Perform at Low Temperatures", Materials Engineering, Vol. 70, No. 7, December, 1969, pp. 34-35, (62975).

Dyment, J. and H. Ziebland, "The Tensile Properties of Some Plastics at Low Temperatures", Journal of Applied Chemistry, Vol. 8, April, 1958, pp. 203-206, (10462).

Jacobs, H. and E. Jenckel, "The Dynamic Mechanical Properties of Polymethane", Makromal Chemistry, Vol. 43, No. 1-2, 1961, pp. 132-143, (14950).

Jolley, C. E., C. A. Homsy and J. A. Reed, "Thermoplastics TFE-FEP Fluorocarbons", Machine Design, Vol. 36, No. 22, September, 1964, pp. 67-73, (23370).

Jolley, C. E., C. A. Homsy and J. A. Reed, "Thermoplastics TFE-FEP Fluorocarbons", Machine Design, Vol. 36, No. 22, September, 1964, pp. 67-73, (23370).

Krotz, A. S., "Mechanical Characteristics of Elastomers", Machine Design, Vol. 32, November, 1960, pp. 146-154, (11617).

Landrock, A. H., "Cryogenic Properties", Encyclopedia of Polymer Science and Technology, Vol. 4, John Wiley and Sons, Inc., New York, 1966, (42104).

Milek, J. T., A Survey Materials Report on Tetrafluoroethylene (TFE), Hughes Aircraft Col, Electronic Properties Information Center, Culver City, California, Report No. EPIC 5-3, September, 1964, (25310).

Miller, R. N., C. D. Bailey, S. M. Freeman, et al,, "Properties of Foams Adhesives and Plastic Films at Cryogenic Temperatures", Industrial Engineering Chemical Product Research and Development, Vol. 1, No. 4, December, 1962, pp. 257-261, (13520).

Mowers, R. E., Final Report - Program of Testing Non-Metallic Material at Cryogenic Temperatures, Rocketdyne, Rocket Propulsion Lab, Edwards, California, Report No. R-3498, December, 1962, (15840).

"New Cryogenic Strength Data for Plastics", Materials in Design Engineering, Vol. 54, No. 3, September, 1961, (21778).

Noonan, J. W., "Materials in the Design of Seals for Extreme Environments", Machine Design, Vol. 34, August, 1962, pp. 186-196, (16860).

Properties of Filled Teflon, Aero-jet General Corporation, Azusa, California, Report No. 63-135, January, 1963, (21489).

"Properties of Teflon", Journal of Teflon, Vol. 8, No. 2, March-April, 1967, pp. 4-7, (43658).

Reid, R. P., R. E. Schramm and A. F. Clark, "Mechanical, Thermal and Electrical Properties of Selected Polymers", Cryogenics, Vol. 13, No. 2, February, 1973, pp. 67-82, (87674).

Robbins, R. F. and R. P. Reed, "Tensile Properties of Neoprene Below the Glass Transition Temperature", Advances in Cryogenic Engineering, Vol. 13, Plenum Press, New York, 1968, pp. 252-258, (45231).

Ruby, J. D., Evaluation of Elastomers for Potential Use at Cryogenic Temperatures, Rock Island Arsenal Lab, Illinois, RIAL Report No. 63-1573, May, 1963, (20724).

Sato, M. and S. Kuma, "Mechanical Properties of Plastics and Synthetic Papers", Cryogenic Engineering, Vol. 8, No. 3, 1973, pp. 95-104, (87498).

Soffer, L. M. and R. Molho, "Mechanical Properties of Epoxy Resins and Glass/Epoxy Composites at Cryogenic Temperatures", Cryogenic Properties of Polymers, Marcel Dekker, Inc., New York, 1968, pp. 87-117, (63603).

Swenson, C. A., "Mechanical Properties of Teflon at Low Temperatures", Review of Scientific Instrumentation, Vol. 25, 1954, pp. 834 835, (141).

Thorne, J. A., "The Effect of Extreme Low Temperatures on Silicone Elastomeric Materials", Cryogenic Technology, Vol. 2, No. 1, June, 1966, pp. 30-31, (36969).

Toth, J. M. and J. R. Barber, "Structural Properties of Glass-Fiber Filament-Wound Cryogenic Pressure Vessels", Advances in Cryogenic Engineering, Vol. 10, Plenum Press, New York, 1965, pp. 134-144, (24059).

Weitzel, D. H. and R. F. Robbins, Behavior of Polymeric Materials at Cryogenic Temperatures, NBS Summary Report, June, 1966, (45030).

Weitzel, D. H., R. F. Robbins and P. R. Ludtke, Elastomeric Seals and Materials at Cryogenic Temperatures, NBS Report No. 8244, April, 1964, (20957).

Wischmann, K. B., A Survey of Low Temperature Polymers, Sandia Labs, Albuquerque, New Mexico, Report No. SC DR 68 898, March, 1969, (66392).

A.4.1.2 Proportional Limit of Polymers

Hertz, J., Tensile Testing of Adlock 851, Adlock PG-LA and Adlock EG-11A-81A from -423 Degrees F to 78 Degrees F, General Dynamics/Convair, San Diego, Report MGR-737, June, 1961, (11849).

A.4.1.3 Elastic Modulii of Polymers

Armeniades, C. D., I. Kuriyama, J. M. Roe and E. Baer, Mechanical Behavior of Polyethylene Terephthalate at Cryogenic Temperatures, Case Institute of Technology, Cleveland, Ohio, Report No. NASA-CR-88270, 1966, (48857).

Athongies, A. D., B. T. Peterson, G. L. Salinger and C. D. Swartz, "Low Temperature Acoustically Measured Specific Heats and Elastic Constants of Four Technical Polymers", Cryogenics, Vol. 12, No. 2, April, 1972, pp. 125-128, (78202).

Bringer, R. P., Fluorocarbon Plastics Under the Influence of Unusual Environmental Conditions, Society of Aerospace Materials and Process Engineers National Symposium, St. Louis, May, 1962, Paper, (15395).

Chamberlain, D. W., "Mechanical Properties Testing of Plastic Laminate Materials Down to 20 Degrees K", Advances in Cryogenic Engineering, Vol. 10, Plenum Press, New York, 1965, pp. 117-125, (23922).

Corruccini, R. J., "Properties of Materials at Low Temperatures", Chemical Engineering Progress, Vol. 53, No. 6, 1957, pp. 262-267, (3891).

Crissman, J., J. A. Sauer and A. E. Woodward, "Dynamic Mechanical Behavior of Some High Polymers at Temperatures from 6 Degrees K", Journal of Polymer Science, Vol. 2, 1964, pp. 5074-5091, (25220).

Crissman, J. M., A. E. Woodward and J. A. Sauer, "Dynamic Mechanical Behavior of Polystyrene and Related Polymers at Cryogenic Temperatures from 4.2 Degrees K", Journal of Polymer Science, Vol. 3, No. 7, July, 1965, pp. 2693-2697, (29643).

Crissman, J. M., A. E. Woodward and J. A. Sauer, "Dynamic Mechanical Behavior of Polystyrene and Related Polymers at Cryogenic Temperatures from 4.2 Degrees K", Journal of Polymer Science, Vol. 3, No. 7, July, 1965, pp. 2693-2697, (29643).

Fahey, N. H., Ultrasonic Determination of Elastic Constants at Room and Low Temperatures, Watertown Arsenal, Mass., Technical Report No. WAL-TR-118.1/1, April, 1960, (8544).

Jolley, C. E., C. A. Homsy and J. A. Reed, "Thermoplastics. TFE-FEP Fluorocarbons", Machine Design, Vol. 36, No. 22, September, 1964, pp. 67-73, (23370).

Massa, D. J., "Measuring the Dynamic Moduli of Glassy Polymers, Analysis of the Rheovibron", Journal of Applied Physics, Vol. 44, No. 6, June, 1973, pp. 2595-2600, (86855).

Morgan, R. J., L. E. Neilson and R. Buchdahl, "Dynamic Mechanical Properties of a Number of Elastomers and Related Polymers from 4 to 250 K", Journal of Applied Physics, Vol. 42, No. 12, November, 1961, pp. 4653-4659, (73698).

Mowers, R. E., Final Report, Program of Testing Nonmetallic Materials at Cryogenic Temperatures, Rocketdyne, Rocket Propulsion Lab, Edwards, California, Report No. R-3498, December, 1962, (15840).

Mowers, R., "Properties of Nonmetallic Materials at Cryogenic Temperatures", Proceedings of the 1918 Summer Study on Superconducting Devices and Accelerators, Upton, New York, April, 1966, (61250).

Reid, R. P., R. E. Schramm and A. F. Clark, "Mechanical, Thermal and Electrical Properties of Selected Polymers", Cryogenics, Vol. 13, No. 2, February, 1973, pp. 67-82, (87674).

Robbins, R. F., Behavior of Polymeric Materials at Cryogenic Temperatures, NBS Summary Report, May, 1967, (54892).

Ward, I. M., "The Mechanical Behavior of Polyethylene Terephthalate", Cryogenic Properties of Polymers, Marcel Dekker, Inc., New York, 1968, pp. 45-72, (63602).

A.4.1.4 Poisson's Ratio of Polymers

Athougies, A. D., B. T. Peterson, G. L. Salinger and C. D. Swartz, "Low Temperature Acoustically Measured Specific Heats and Elastic Constants of Four Technical Polymers", Cryogenics, Vol. 12, No. 2, April, 1972, pp. 125-128, (78202).

Fahey, N. H., Ultrasonic Determination of Elastic Constants at Room and Low Temperatures, Watertown Arsenal Labs, Mass., Technical Report No. WAL-TR-118.1/1, April, 1960, (8544).

A.4.1.5 Elongation and Reduction in Area of Polymers

Skelton, J., W. D. Freeston and M. M. Schoppee, "The Effect of Internal Temperature Rise on the Tensile Behavior of Polymeric Materials at Subambient Temperatures", Journal of Applied Polymeric Science, Vol. 14, No. 11, November, 1970, pp. 2797-2814, (75192).

Washburn, R. M. and D. W. Karle, "New Polymers for Thermal Extremes", Industrial Research, Vol. 9, October, 1967, pp. 94-99, (55140).

A.4.1.6 Torsional Properties of Polymers

Armeniades, C. D., I. Kuriyama, J. M. Roe and E. Baer, Mechanical Behavior of Polyethylene Terephthalate at Cryogenic Temperatures, Case Institute of Technology, Cleveland, Ohio, Report No. NASA-CR-88270, 1966, (48857).

Athougies, A. D., B. T. Peterson, G. L. Salinger and C. D. Swartz, "Low Temperature Acoustically Measured Specific Heats and Elastic Constants of Four Technical Polymers", Cryogenics, Vol. 12, No. 2, April, 1972, pp. 125-128, (78202).

Fahey, N. H., Ultrasonic Determination of Elastic Constants of Room and Low Temperatures, Watertown Arsenal Labs, Mass., Technical REport No. WAL-TR-118.1/1, April, 1960, (8544).

Frosini, V. and A. E. Woodward, "Effects of Orientation on Dynamic Shear Behavior of Some Amorphous Polymers from 4.2 Degrees to 300 Degrees K", Journal of Polymer Science, Vol. 7, No. 3, 1969, pp. 525-536, (61909).

Jacobs, H. and E. Jenckel, "The Dynamic Mechanical Properties of Polyurethane", Makromolecular Chemistry, Vol. 43, No. 1-2, 1961, pp. 132-143, (14950).

Lieb, J. H. and R. Mowers, "Problems in Evaluating and Testing Plastics", Material Design Engineering, Vol. 53, July, 1961, pp. 115-118, (42962).

"Properties of Teflon at Cryogenic Temperatures", Journal of Teflon, Vol. 8, No. 2, March-April, 1967, pp. 4-7, (43658).

Saam, J. C. and F. W. G. Fearon, "Properties of Polystyrene-Polydimethylsiloxane Block Copolymers", Industrial Engineering Chemical Production Research and Development, Vol. 10, No. 1, March, 1971, pp. 10-14, (70232).

Tensile Properties of Three Thermoplastics, Office of Technical Services, Washington, D.C., Report No. PBX-151-573, (9114).

A.4.1.7 Notch Toughness of Polymers

Armeniades, C. D., I. Kuriyama, J. M. Roe and E. Baer, Mechanical Behavior of Polyethylene Terephthalate at Cryogenic Temperatures, Case Institute of Technology, Cleveland, Ohio, Report No. NASA-CR-88270, 1966, (48857).

Metallurgy, Lawrence Radiation Lab, Berkeley, California, Report No. UCRL-18043, March, 1968, (57008).

Soffer, L. M. and R. Molho, "Mechanical Properties of Epoxy Resins and Glass/Epoxy Composites at Cryogenic Temperatures", Cryogenic Properties of Polymers, Marcel Dekker, Inc., New York, 1968, pp. 87-117, (63603).

A.4.1.8 Fatigue Properties of Polymers

Brink, N. O., Determination of the Performance of Plastic Laminates Under Cryogenic Temperatures, Narmco Research and Development, San Diego, Report No. ASD-TDR-62-794, August, 1962, (15516).

Brink, N. O., "Mechanical Behavior of Reinforced Plastics at Cryogenic Temperatures", SPE Journal, Vol. 20, October, 1964, pp. 1123-1131, (25613).

Chamberlain, D. W., B. R. Lloyd and R. L. Tennent, Determination of the Performance of Plastic Laminates at Cryogenic Temperatures, Narmco Research and Development, Report No. ASD-TDR-62-794, March, 1964, (23324).

Chamberlain, D. W., "Tensile Fatigue Testing at Temperatures Down to 20 Degrees K", Advances in Cryogenic Engineering, Vol. 9, Plenum Press, New York, 1963, pp. 131-138, (17403).

Hertz, J., The Effect of Cryogenic Temperatures on the Mechanical Properties of Reinforced Plastic Laminates, General Dynamics/Astronautics, San Diego, Quarterly Progress Report No. 4, May, 1963, (17919).

Lefave, G. M., R. Gamero and H. H. Moore, Elastomers for Use in Cryogenic Environments, 7th National SAMPE Symposium on Adhesives and Elastomers for Environmental Extremes, Los Angeles, May, 1964, (25516).

A.4.2 Thermophysical Properties of Polymers

A.4.2.1 Thermal Conductivity of Polymers

Anderson, D. R., "Thermal Conductivity of Polymers", Chemical Review, Vol. 66, No. 6, December, 1966, pp. 677-690, (40856).

Barron, R. F., "Low Temperature Properties of Engineering Materials", Machine Design, Vol. 32, March, 1960, pp. 189-195, (10356).

Burnier, P. H., "Materials", Bulletin Institut International Du Froid, Annexe 1969-1971, pp. 339-364, (71753).

Campbell, M. D., G. L. O'Barr and J. Hertz, Thermophysical Properties of Plastic Materials and Composites to Liquid Hydrogen Temperatures, General Dynamics/Astronautics, San Diego, Report No. BVJ-63-001-8, November, 1964, (28393).

Dillard, D. S. and K. D. Timmerhaus, Thermal Transport Properties of Selected Solids at Low Temperatures, 16th Annual AICHE Meeting, New York, November, 1967, Paper 30A, (49650).

Eiermann, K., The Thermal Conductivity of High Polymers, American Chemical Society Abstract Paper, No. 145, 1963, (38079).

Hertz, J. and J. F. Haskins, "Thermal Conductivity of Reinforced Plastics at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 10, Plenum Press, New York, 1965, pp. 163-170, (34339).

Hertz, J., J. F. Haskins, J. L. Percy and M. D. Campbell, The Determination of Thermophysical Properties of Plastic Materials and Composites, General Dynamics/Astronautics, San Diego, Quarterly Progress Report No. 4, July, 1963, (19540).

Kolouch, R. L. and R. G. Brown, "Thermal Conductivities of Polyethylene and Nylon from 1.2 Degrees to 20 Degrees K", Journal of Applied Physics, Vol. 39, No. 8, July, 1968, pp. 3999-4003, (52580).

Kondraciuk, B., R. Rafalowicz and B. Sujak, "Thermal Conductivity of High Pressure and Low Pressure Polyethylene in the Temperature Range from 3 to 300 K", Acta Physical Polonia, Vol. A41, No. 2, February, 1972, pp. 141-148, (78151).

Kropschot, R. H., "Multiple Layer Insulation for Cryogenic Applications", Cryogenics, Vol. 1, No. 3, March, 1961, pp. 171-177, (10639).

Loser, J. B. and C. E. Moeller, Thermophysical Properties of Thermal Insulating Materials, Midwest Research Institute, Kansas City, Mo., Report No. ML-TDR-64-5, April, 1964, (24560).

"Low Temperature Insulations - Foams and Composites", Cryogenic Engineering News, Vol. 4, No. 5, May, 1969, pp. 20-25, (59379).

Luikov, A. V., L. L. Vasiliev and A. D. Shuyrev, "Experimental Determination of Thermophysical Properties of Polymer Materials Within 10 to 300 K", Progress in Refrigeration Science and Technology, Vol. 1, Avi Publishing Co., Inc., Westport, Conn., pp. 637-641, (87285).

Moeller, C. E., J. B. Loser, W. E. Snyder and V. Hopkins, Thermophysical Properties of Thermal Insulating Materials, Midwest Research Institute, Kansas City, Mo., Technical Documentary Report No. ASD-TDR-62-215, July, 1962, (13888).

Probert, S. P., "Thermal Insulation", Chemical Process Engineering, Heat Transfer Survey, 1968, pp. 175-180, (52758).

Reed, R. P., P. E. Schramm and A. F. Clark, "Mechanical, Thermal and Electrical Properties of Selected Polymers", Cryogenics, Vol. 13, No. 2, February, 1973, pp. 67-82, (87674).

Reese, W., "Temperature Dependence of the Thermal Conductivity of Amorphous Polymers", Journal of Applied Physics, Vol. 37, No. 8, July, 1966, pp. 3227-3230, (38733).

Reese, W., "Low Temperature Thermal Conductivity of Amorphous Polymers", Journal of Applied Physics, Vol. 37, No. 2, February, 1966, pp. 864-868, (34958).

A.4.2.2 Specific Heat of Polymers

Athougies, A. D., B. T. Peterson, G. L. Salinger and C. D. Swartz, "Low Temperature Acoustically Measured Specific Heats and Elastic Constants of Four Technical Polymers", Cryogenics, Vol. 12, No. 2, April, 1972, pp. 125-128, (78202).

Boerio, F. J. and D. D. Cornell, "Heat Capacity of Polyoxymethylene", Journal of Polymer Science, Vol. 11, No. 2, January, 1973, pp. 391-392, (85709).

Burnier, P. H., "Materials", Bulletin Institut International Du Froid, Annexe 1969-1, pp. 339-364, (71753).

Campbell, M. D., J. F. Haskins and G. L. O'Barr, Experimental Evaluation of the Thermophysical Properties of Some Plastics and Composites at Cryogenic Temperatures, 2nd Annual AIAA Meeting, San Francisco, July, 1965, Paper No. 65-423, (30547).

Clegg, G. A., D. R. Gee and T. P. Melia, "Thermal Properties of Ethylene/Propylene Copolymers", Makromolecular Chemistry, Vol. 116, 1968, pp. 130-139, (56308).

Dillard, D. S. and K. D. Timmerhaus, Thermal Transport Properties of Selected Solids at Low Temperatures, 16th Annual AICHE Meeting, New York, November, 1967, Paper 30A, (49650).

Morrison, J. A. and D. M. T. Newsham, "Comment on Heat Capacity of Polyethylene from 2.5 Degrees to 30 Degrees K", Journal of Chemistry and Physics, Vol. 47, No. 7, October, 1967, pp. 2511-2512, (47220).

Noer, R. J., C. W. Dempsey and J. E. Gordon, "Low Temperature Specific Heats of Three Plastics", Bulletin of American Physics Society, Vol. 4, 1959, pp. 108-109, (4627).

Noer, R. J., C. W. Dempsey and J. E. Gordon, "Low Temperature Specific Heats of Three Plastics", Bulletin of American Physics Society, Vol. 4, 1959, pp. 108-109, (4627).

Passaglia, E. and H. K. Kevorkian, "Specific Heat of Atactic and Isotactic Polypropylene andthe Entropy of Glass", Journal of Applied Physics, Vol. 34, 1963, pp. 90-97, (20443).

Reid, R. P., R. E. Schramm and A. F. Clark, "Mechanical, Thermal and Electrical Properties of Selected Polymers", Cryogenics, Vol. 13, No. 2, February, 1973, pp. 67-82, (87674).

Reese, W., "Low Temperature Excess Heat Capacity in Glassy Polymers", Journal of Applied Physics, Vol. 37, No. 11, October, 1966, pp. 3959-3961, (39825).

Reese, W., "Low Temperature Thermal Conductivity of Amorphous Polymers", Journal of Applied Physics, Vol. 37, No. 2, February, 1966, pp. 864-868, (34958).

Sochava, I. V., Specific Heat of Polymethylmethacrylate and Polystyrene at Low Temperatures, NTIS Accession Number 63-13402, 1961, (18864).

Tucher, J. E. and W. Reese, "Heat Capacity of Polyethylene from 2.5 Degrees to 30 Degrees K", Journal of Chemistry and Physics, Vol. 46, No. 4, February, 1967, pp. 1388-1397, (42990).

Warfield, R. W. and M. C. Petree, Heat Capacity of Amorphous Polymers at Low Temperatures, U. S. Naval Ordnance Lab, White Oak, Md., Report No. NOLTR-61-163, November, 1961, (13133).

Warfield, R. W. and M. C. Petree, Thermodynamic Properties of Polybutene-1 and Butene-1, U. S. Naval Ordnance Lab, White Oak, Md., Report No. NOLTR 66-171, September, 1966, (42906).

Warifeld, R. W. and M. C. Petree, Thermodynamic Properties of Polyethylene, U. S. Naval Ordnance Lab, White Oak, Md., Technical Report No. 61-92, August, 1961, (12171).

Warfield, R. W. and M. C. Petree, Thermodynamic Properties of Poly-Styrene and Styrene, U. S. Naval Ordnance Lab, White Oak, Md., NAVWEPS Report No. 7352, September, 1960, (14831).

Wunderlich, B. and L. P. Jones, "Heat Capacities of Solid Polymers", Journal of Micromolecular Science, Serial B, Vol. 3, March, 1969, pp. 67-79, (64351).

A.4.2.3 Thermal Expansion of Polymers

Bailey, C. D., Linear Thermal Expansion of Organic Materials at Cryogenic Temperatures, Lockheed Aircraft Co., Marietta, Ga., Report No. ER-5682, May, 1962, (14801).

Bringer, R. P., "Thermoplastics CTFE Fluorcarbons", Machine Design, Vol. 36, No. 22, September, 1964, pp. 73-75, (23371).

Campbell, M. D., "Thermal Expansion Characteristics of Some Plastic Materials and Composites from Room Temperature to -253 Degrees C", Advances in Cryogenic Engineering, Vol. 10, Plenum Press, New York, 1965, pp. 154-162, (23929).

Campbell, M. D., J. F. Haskins and G. L. O'Barr, Experimental Evaluation of the Thermophysical Properties of Some Plastics and Composites at Cryogenic Temperatures, 2nd Annual AIAA Meeting, San Francisco, July, 1965, Paper No. 65-423, (30547).

Corruccini, R. J., "Properties of Materials at Low Temperatures", Chemical Engineering Progress, Vol. 53, No. 6, 1957, pp. 262-267, (3891).

Corruccini, R. J. and J. J. Gniewek, Thermal Expansion of Technical Solids at Low Temperatures, NBS Monograph 29, May, 1961, (11486).

Dillard, D. S. and K. D. Timmerhaus, Thermal Transport Properties of Selected Solids at Low Temperatures, 16th Annual AICHE Meeting, New York, November, 1967, Paper 30A, (41650).

Gillespie, L. R., D. O. Saxton and F. M. Chapman, "A New Design Data for TFE (A New Fluorocarbon Plastic) and TFE (The Proved Standard Fluorocarbon)", Machine Design, Vol. 32, February, 1960, pp. 156-162, (10802).

Haldon, R. A. and R. Shima, "Thermal Expansivities of Polymers at Cryogenic Temperatures", Macromolecules, Vol. 1, No. 4, August, 1968, pp. 340-343, (56979).

Hamilton, W. D., D. B. Greene and D. E. Davidson, "Thermal Expansion of Epoxies Between 2 and 300 Degrees K", Review of Scientific Instrumentation, Vol. 39, No. 5, May, 1968, pp. 645-648, (50789).

Haskins, J. F., Measured Values for the Coefficients of Linear Expansion of Polyal 420 and Conolon 506 at Low Temperatures, General Dynamics/Astronautics, San Diego, Report MGR-154, May, 1960, (11851).

Haskins, J. F., J. Hertz and M. D. Campbell, The Determination of Thermophysical Properties of Plastic Materials and Composites at Cryogenic Temperatures, General Dynamics/ Astronautics, San Diego, Quarterly Progress Report No. 1, July-October, 1962, (15187).

Hertz, J., J. F. Haskins, J. L. Percy and M. D. Campbell, The Determination of Thermophysical Properties of Plastic Materials and Composites at Cryogenic Temperatures, General Dynamics/Astronuatics, San Diego, Quarterly Progress Report No. 4, July, 1963, (19540).

Jolley, C. E., C. A. Homsy and J. A. Reed, "Thermoplastics. TFE-FEP Flurocarbons", Machine Design, Vol. 36, No. 22, September, 1964, pp. 67-73, (23370).

Mathes, K. N., "Electrical and Mechanical Behavior of Polymers at Cryogenic Temperatures", SPE Journal, Vol. 20, No. 7, July, 1964, pp. 634-637, (23759).

Mathes, K. N., "Properties of Dielectrics at Cryogenic Temperatures", Dielectrics in Space Symposium Westinghouse Research Labs, Collected Paper, Pittsburgh, Pa., Paper No. 10, July, 1963, (21215).

Mowers, R. E., Final Report, Program of Testing Non-Metallic Materials at Cryogenic Temperatures, Rocketdyne, Rocket Propulsion Lab, Edwards, Calif., Report No. R-3498, December, 1962, (15846).

"Properties of Teflon at Cryogenic Temperatures", Journal of Teflon, Vol. 8, No. 2, March-April, 1967, pp. 4-7, (43658).

Reed, R. P., R. E. Schramm and A. F. Clark, "Mechanical, Thermal and Electrical Properties of Selected Polymers", Cryogenics, Vol. 13, No. 2, February, 1973, pp. 67-82, (87674).

Robbins, R. F., Y. Ohori and D. H. Weitzel, "Linear Thermal Expansion of Elastomers in the Range 300 Degrees K to 76 Degrees K", Advances in Cryogenic Engineering, Vol. 8, Plenum Press, New York, pp. 287-299, (13329).

Robbins, R. F., D. H. Weitzel and R. N. Herring, "The Application and Behavior of Elastomers at Cryogenic Temperatures", Advances in Cryogenic Engineering, Vol. 7, Plenum Press, New York, 1962, pp. 343-352, (41270).

Weitzel, D. H., R. F. Robbins and R. N. Herring, Elastomeric Seals and Materials at Cryogenic Temperatures, NBS Report No. 6749, March, 1961, (11783).

A.4.2.4 Density of Polymers

Beecroft, R. I. and C. A. Swenson, "Behavior of Polytetrafluoroethylene (Teflon) Under High Pressures", Journal of Applied Physics, Vol. 30, No. 11, November, 1959, pp. 1793-1798, (12529).

Brink, N. D., Determination of the Performance of Plastic Laminates Under Cryogenic Temperatures, Narmco Research and Development, San Diego, Report No. ASD-TDR-62-794, August, 1962, (15516).

Haskins, J., J. Hertz and M. D. Campbell, The Determination of Thermophysical Properties of Plastic Materials and Composites at Cryogenic Temperatures, General Dynamics/Astronautics, San Diego, Quarterly Progress Report No. 1, July-October, 1962, (15187).

Skibukawa, T. and V. D. Gupta, Temperature Dependence of Modulus and Density of Nylon-6, Textile Research Institute, Princeton, N. J., Technical Report No. 30, August, 1962, (15153).

Tucher, J. E. and W. Reese, "Heat Capacity of Polyethylene from 2.5 Degrees to 30 Degrees K", Journal of Chemical Physics, Vol. 46, No. 4, February, 1967, pp. 1388-1397, (42990).

A.4.3 Electrical Conductivity of Polymers

Chan, W. S. and A. K. Jonscher, "Structural and Electrical Properties of Solid Polymeric Carbon Disulphide", Physical Status Solidi, Vol. 32, No. 2, April, 1969, pp. 749-761, (61027).

"Properties of Teflon at Cryogenic Temperatures", Journal of Teflon, Vol. 8, No. 2, March-April, 1967, pp. 4-7, (43658).

A.4.4 Magnetic Properties of Polymers

Hord, G. M., "Low Temperature Magnetic Susceptibility of Pyrex, Fused Quartz and Polytetrafluoroethylene", Review of Scientific Instrumentation, Vol. 37, No. 4, April, 1966, pp. 515-516, (35228).

Salinger, G. L. and J. C. Wheatley, "Magnetic Susceptibility of Materials Commonly Used in the Construction of Cryogenic Apparatus", Review of Scientific Instrumentation, Vol. 32, No. 7, July, 1961, pp. 872-874, (12728).

BIBLIOGRAPHY

1. Thullen, P., Analysis of the Application of Superconductivity to Commercial Electric Power Generation, M.I.T. Thesis, Sc.D., M.E., (1969).

2. Woodson, H. H., J. L. Smith, Jr., P. Thullen and J. L. Kirtley, Jr., "The Application of Superconductors in the Field Windings of Large Synchronous Machines", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-90, No. 2, March/April, 1971, pp. 620-627.

3. Woodson, H. H., "Applications of Superconductivity and Cryogenics in Electric Power Systems", Advances in Cryogenic Engineering, Vol. 16, K. D. Timmerhaus, ed., Plenum Publishing Corporation, New York, 1971, pp. 1-10.

4. Greene, David L., Analysis of a Marine Propulsion System Incorporating Superconducting Electrical Machinery, M.I.T. Thesis, Ph.D., M.E., (1970).

5. Kirtley, James L., Jr., Design and Construction of an Armature for an Alternator with a Superconducting Field Winding, M.I.T. Thesis, Ph.D., E.E., (1971).

6. Laine, Lawrence L., Superconducting Alternators for Marine Propulsion, M.I.T. Thesis, M.S., O.E., (1967).

7. Samans, Carl H., Metallic Materials in Engineering, The Macmillan Company Limited, London, (1963).

8. Faires, Virgil Moring, Design of Machine Elements, The Macmillan Company, New York, (1964).

9. Oberg, Erik and Franklin D. Jones, Machinery's Handbook, A Reference Book for the Mechanical Engineer, Draftsman, Toolmaker and Machinist, Industrial Press, Inc., New York, (1971).

10. Lyman, Taylor, ed., Metals Handbook, 1948 Edition, The American Society for Metals, Cleveland, Ohio, (1948).

11. Wulff, John, Howard F. Taylor and Amos J. Shaler, Metallurgy for Engineers; Casting, Welding, and Working, John Wiley and Sons, Inc., New York, (1960).

12. Masubuchi, Koichi, Materials for Ocean Engineering, The M.I.T. Press, Cambridge, Massachusetts, (1970).

13. Peterson, R. E., Stress Concentration Design Factors, John Wiley and Sons, Inc., New York, (1966).

14. Jakob, Max, Heat Transfer, John Wiley and Sons, Inc., New York, (1949).

15. Rohsenow, W. M. and H. Y. Choi, Heat, Mass and Momentum Transfer, Prentice-Hall, Inc., Englewood Cliffs, N. J., (1961).

16. Barron, Randall, Cryogenic Systems, McGraw-Hill Book Company, Inc., New York, (1966).

17. Rose-Innes, A. C., Low Temperature Techniques, The English Universities Press, Ltd., London, (1964).

18. Scott, Russell B., Cryogenic Engineering, D. Van Nostrand Company, Inc., Princeton, N. J., (1967).

19. Zemensky, Mark W., Heat and Thermodynamics, McGraw-Hill Book Company, Inc., New York, (1957).

20. Keenan, Joseph H., Thermodynamics, John Wiley and Sons, Inc., New York, (1963).

21. Fitzgerald, A. E. and D. E. Higginbotham, Basic Electrical Engineering, McGraw-Hill Book Company, Inc., New York, (1957).

22. Del Toro, Vincent, Principles of Electrical Engineering, Prentice-Hall, Inc., Englewood Cliffs, N. J. (1965).

23. Schwartzberg, F. R., et al., Cryogenic Materials Data Handbook, Volume I and Volume II, National Technical Information Service, Springfield, Virginia, (1970).

24. Johnson, Victor J., ed., A Compendium of the Properties of Materials at Low Temperatures, National Technical Information Service, Springfield, Virginia, (1961).

25. Timmerhaus, K. D., ed., Advances in Cryogenic Engineering, Volumes 1-18, Plenum Press, New York.

26. Proceedings of the 1972 Applied Superconductivity Conference, Order Department, IEEE, 345 East 47 Street, New York, (1972).

27. McClintock, R. Michael and Hugh P. Gibbons, Mechanical Properties of Structural Materials at Low Temperatures, NBS Monograph 13, U.S. Government Printing Office, Washington, D.C., (1960).

28. Reed, Richard P. and Ritchie P. Mitchell, Low Temperature Mechanical Properties of Copper and Selected Copper Alloys, NBS Monograph 101, U.S. Government Printing Office, Washington, D.C., (1967).

29. Childs, Gregg E., Lewis J. Ericks and Robert L. Powell, Thermal Conductivity of Solids at Room Temperature and Below, NBS Monograph 131, U.S. Government Printing Office, Washington, D.C., (1973).

30. Parker, Earl R., Materials Data Book, McGraw-Hill Company, New York, (1967).

31. Uhlig, Herbert H., Corrosion and Corrosion Control, John Wiley and Sons, Inc., New York, (1971).

32. Campbell, J. E., Review Of Current Data on the Tensile Properties of Metals at Low Temperatures, Battelle Memorial Institute, DMIC Report No. 148, (14 February 1961)

33. Hurlich, A., "Materials for Cryogenic Applications", Research and Development, (August, 1970), pp. 28-29.

34. Low Temperature and Cryogenic Steels, Materials Manual, United States Steel Corporation, ADUSS-01-1206, Pittsburgh, Pennsylvania, (1964).

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